PHYSICS

FOR MIDDLE SCHOOLS

TEXT 3

Experimental Edition

NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

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PREFACE

The Education Commission while discussing the structure of education in our schools and colleges recommended that teaching of science should commence at Class V with Physics and Biology as separate disciplines. It was also suggested that teaching of Chemistry should commence a year later In response to this recommendation, the Chairman, University Grants Commission, New Delhi, appealed to men of science in universities to get together to prepare curricular material for the middle school with a view to improving teaching of Physics in schools The response to this appeal was immediate and enthusiastic Four study groups were constituted, each comprising of research scientists, university professors and school teachers, to develop curricular materials The present book is the third in the series.

The Physics Study Group, after long deliberations, considered it necessary to initiate a new approach to the study of Physics at the school level This approach is essentially based on the active participation of students in the learning process through experimentation, supplemented by demonstration by teachers and discussion leading to the understanding of the basic concepts in Physics. The efforts of the Group have been to relate, as far as possible, the teaching of Physics to what a student sees and does in everday life. In addition, it is intended to transmit, in some measure, the thrill and excitement of doing experiments which would help students to understand Physics and find something new for themselves. Thus the main emphasis is on the process of science rather than on the product of science

In order to enable the students to perform experiments, the Group has developed simple and inexpensive kits which form an integral part of the instruction material. Experiments to be demonstrated by the teachers have also been indicated,

The directors and members of the Study Groups are conscious of the shortcomings and limitations of the material. The practical difficulties in implementing the course will become clear after full-scale trial. Teachers in both urban and rural schools are our primary concern and we look forward to a meaningful appraisal of the material We also look forward to the reaction of the young students to whom it is addressed. We look up to the senior physicists in universities and other institutions for their mature criticism of the material presented here from the standpoint of the contents as well as of the way of presentation. For these reasons, the present edition is being brought out as an experimental edition which will undergo revision after the feedback from various sources

All my colleagues join me in offering our grateful thanks to Professor D S. Kothari, Chairman, University Grants Commission, who conceived this idea, for guidance and stimulation; Shri L S. Chandrakant, Joint Educational Adviser, Ministry of Education, Dr. S. V C Aiya, Director, NCERT; Dr. M. C. Pant, Head of the Department of Science Education and Shri G S Baderia of the NCERT who helped in this endeavour in many ways.

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1.1 Introduction

Now that you have got some idea about distances and measurements, try to stretch your vision a little more. What are the farthest objects you can see with the naked eye, that is, without looking through a telescope? The stars, of course, you will immediately answer. You are perfectly right. The heavens above us are studded with numerous dots of light, known as stars. They are so far away that it is absurd to speak of their distance in terms of kilometers or by any of the methods you have learnt. How do you find out how far they are?

The stars are recognised by their lights, however faint they may be. This takes you to another important lesson you have learnt by now about the source of light. You have done some experiments with light and have some idea of its nature and properties. The sun is one of the stars in the universe. All the twinkling lights which you see in the night sky are coming from other stars, many millions of metres away from you. They are all sources of light. Naturally you would be curious to know something about them.

1.2 How many Stars are there in the Sky?

Once upon a time there was a Mr. Know-all who claimed that he knew everything in the universe. The king heard of this and summoned him. "I am going to ask you a very tough question. If you can give me the answer, well and good. If not, I'll cut off your head". Then he asked him, "How many stars are there in the sky?" Mr. Know-all promptly replied "three hundred million fifty thousand five hundred and five. You can count and find out for yourself".

We are not told if the king really believed him. But suppose you were asked the same question, would it not be useful to know the correct answer? According to experts not more than six thousand stars are visible to the naked eye. This will not be challenged, as it has been calculated and verified by many astronomers. Of course you can always get a better view with telescopes. They magnify many times. There are telescopes now in use with diameters going up to 200 inches (5 m). The most powerful so far is housed in Mt. Palomar observatory,

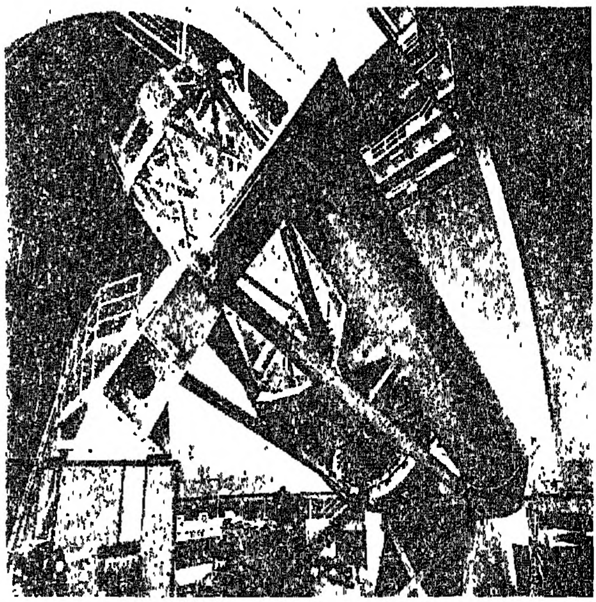


Fig. 1.1

U.S A. (figure 1.1). In our country the Nizamiah Observatory at Hyderabad has a 48 inches (1.2 m) diameter telescope.

1.3 Aristotle and the Heavens

Aristotle was a great Greek philosopher who lived in the 4th century before Christ (384-322 B.C.). Like

many learned men before him he thought deeply about the heavens. The conclusions he arrived at may seem very curious to you but for many many centuries after him—his theory was considered to be the most correct. Of course his mistakes were corrected later by other men, but it would be interesting to know what Aristotle had to say about the stars.

The earth, said Aristotle, is at the centre of the universe. The sun, the moon and the planets moved round the earth. But how did they move? Aristotle had a wonderful answer for this. He said each planet was stuck on a transparent sphere. The entire sphere moved along with the planet. On the eighth sphere all the stars were stuck. The stars were fixed and perfect. This, in brief is Aristotle's theory of the heavens. You can very well think for yourself and find out where and how he was wrong.

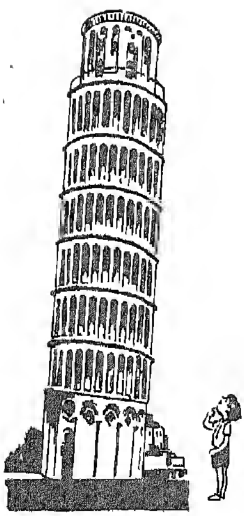
1.4 Copernicus and the Heavens

The idea of a moving earth, as a planet going round the sun was first put forward by the great Polish astronomer Copernicus. It was a great discovery, but Copernicus was afraid to say anything against popular belief and his book was not published till he died in 1543. Even in the 16th century, there were no telescopes and the astronomers used very crude instruments for observation. After observing the stars for many years, Copernicus found the Aristotelian idea to be completely wrong. He was convinced that though the moon went round the earth, other planets moved round the sun. The earth was not by any means, the centre of the universe. The stars appeared to move only because of the earth's rotation round its axis.

1.5 Kepler and Galileo

Copernicus' book was so difficult that very few people really understood it. But as time went on, it attracted intelligent people. Among them were scientists and astronomers like Kepler and Galileo. Kepler went one step ahead in proving that the theory of Copernicus was right. Kepler first proved that the planets move in elliptical orbits and not in circular orbits, as was previously supposed. He also established three laws regarding the motion of planets. They are known as Kepler's laws You will read about them later.

Galileo was a friend of Kepler and like him was a follower of the Copernican system. The name of Galileo must be familiar to you. It was he who made that famous experiment on falling bodies at Pisa. He is remembered for other reasons as well. In 1609 he heard that an eye-glass manufacturer of Venice had made a special glass which could magnify objects. With these glasses Galileo built the first telescope. He was also the first man to use this telescope in watching the heaven.



1.6 What did Galileo See?

The telescope was naturally a great help and Galileo could see the heavenly bodies far more distinctly than other astronomers could before him. The moon being the closest object he observed it in great detail He found the surface of the moon to be uneven, full of hills and valleys. The photographs of the surface of the moon must be quite familiar to you to-day. In fact even moon maps are available now. But Galileo was the first man to see the surface of the moon. He saw that the high mountains had cast long shadows and from this, he was able to calculate their height.

Fig 1.2 (a)

Fig 1.2 (b)

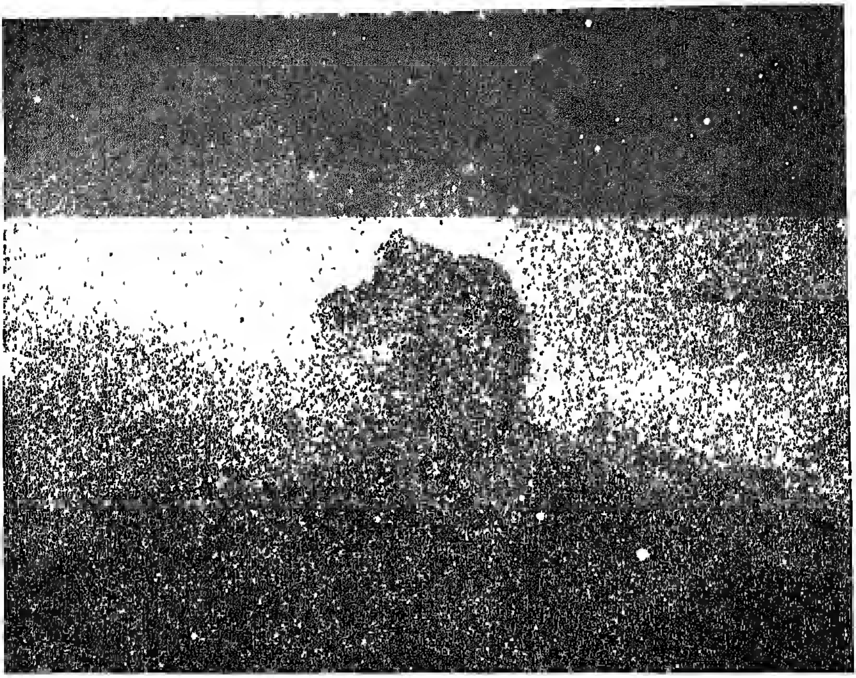


Fig. 1 2 (c)

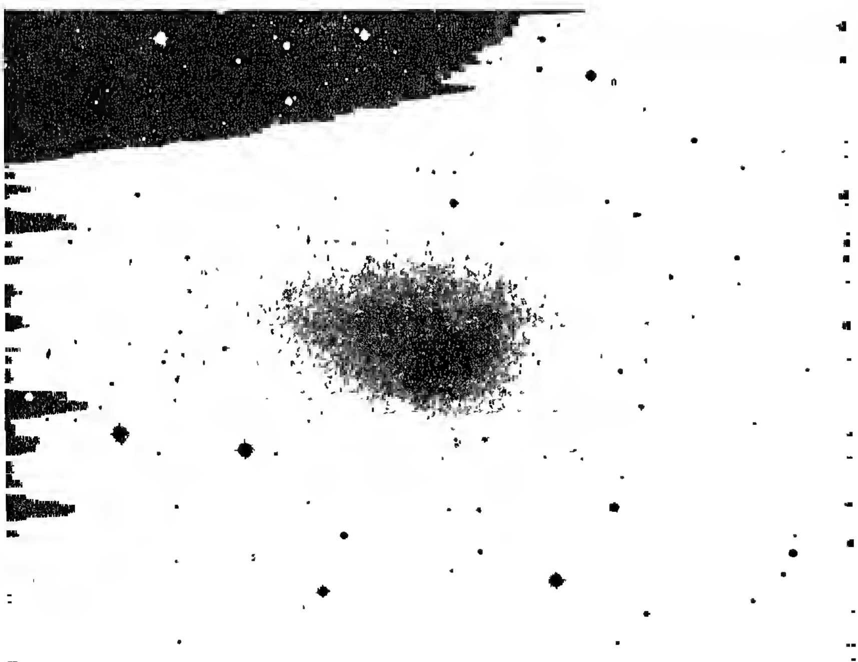


Fig 1 2 (d)

The telescope also enabled him to discover the four *satellites of Jupiter* and the *ring of Saturn*. His telescope was not powerful enough to observe the entire ring, but he saw two small bodies on either side of Saturn He observed that Venus had phases and from this he concluded that Venus moved round the sun. He saw other interesting things such as *sunspots*—dark patches on the sun—which seemed to move. Another important finding of Galileo was about the *Milkyway*. He saw that it was an assembly of thousands of faint stars. You must have noticed in the night sky a broad irregular band of misty light cutting across the sky approximately in the north-south direction. This band is known as the Milkyway

1.7 The Universe as you know now

As was mentioned earlier you can see nearly 6,000 stars with your naked eye. If you use a small telescope you can see 100,000 stars. Through the 200″ telescope nearly twenty thousand million stars are visible. How are these stars distributed in space? It has been found that stars appear in the universe in clusters. Each family of star clusters is called a *galaxy*. All galaxies do not look the same. Some of them are elliptic or spheroidal, some are spiral and some are irregular in shape (figure 1.2). Each galaxy has a nucleus or *galactic centre*. The galaxies rotate about their own centres. The galaxy to which our sun belongs is known as the milkyway It is a spiral galaxy, of the shape of a poached egg hanging in space. The diameter along side is about 150,000 *lightyears* and thickness is about 20,000 lightyears. One lightyear is the distance travelled by light in one year and is approximately $9 \cdot 5 \times 10^{12}$ km The sun is situated at a distance of 30,000 lightyears from the

galactic centre. The sun revolves round the galactic centre once in 250 million years which is called one *cosmicyear*. It is now known that the age of the earth is 3,500 to 4,000 million years. So that the earth is only 14 to 16 cosmicyears old. There are about 150,000 million stars in our galaxy. You might be interested to know that the star nearest to our sun is called α-*Centauri* and is at a distance of 4.3 lightyears from the earth.

How does the universe look if one views through the telescope? As you go past your own galaxy there would be void—dark blank space for thousands of lightyears and then would appear a cluster of stars—a galaxy of several thousand stars. The nearest galaxy Andromeda (figure 1.3) is 800,000 lightyears away. Incidentally Andromeda is visible to the naked eye and can be distinguished as a faint blur against a clear moonless sky. Thus you can claim that you can see upto 800,000 lightyears with your naked eye.

As the telescope is focussed to space beyond your own galaxy you come across another blank space, then a cluster of stars, blank space and cluster of stars again and so on. How far does the universe extend? This is a very difficult question to answer. As far as is known with the help of optical and radio telescopes the farthest stellar bodies are at a distance of about 10^{10} lightyears away. That means the light you receive now from these stars actually started 10^{10} years ago. Thus when you look far out in space you are actually looking back in time. This is a very interesting point. When interplanetary flights become a regular practice this problem of time adjustment is bound to gain in importance.

Fig 1 3

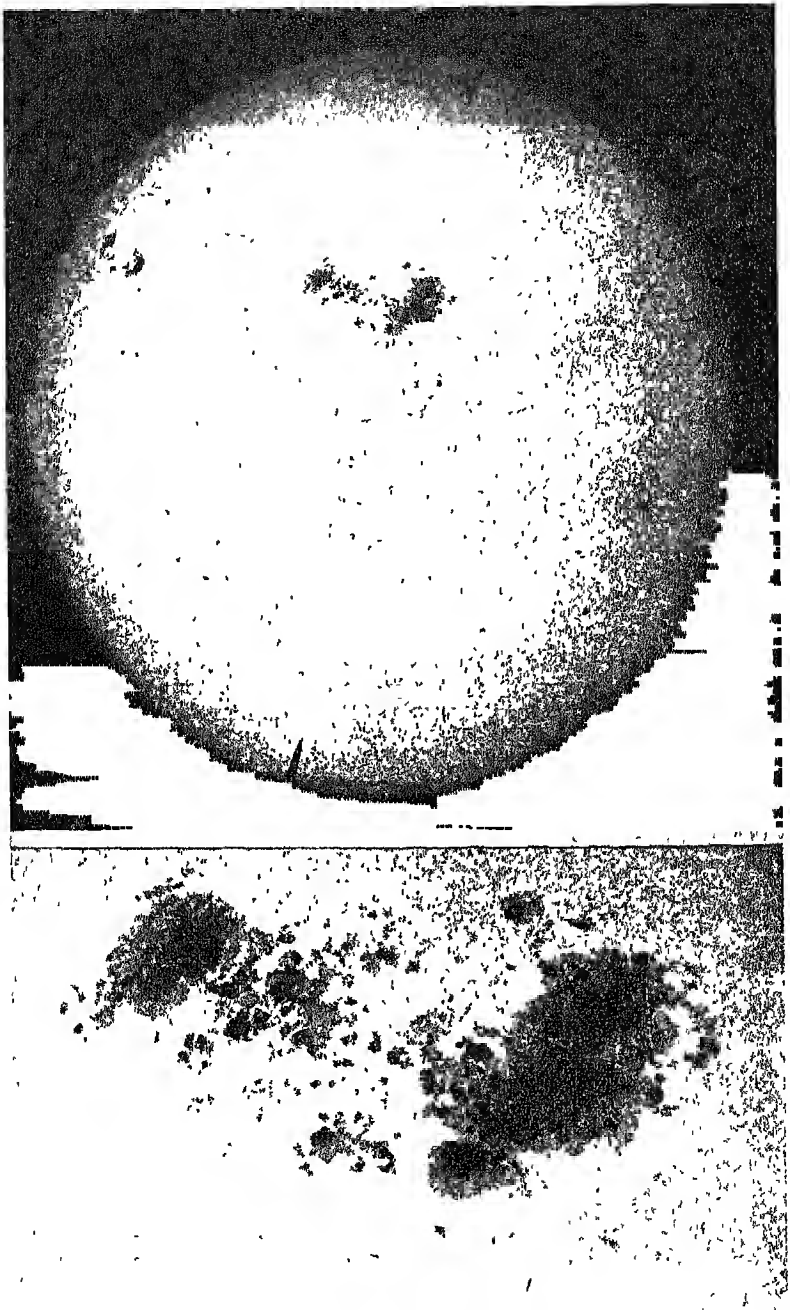


Fig 1.4

1.8 The Sun

The sun is an average-sized star in the sky. To the naked eye it appears like a disc with a well defined boundary, with a slight yellow colour. The average distance of the sun from the earth is 14.96×10^7 km. which is equal to 8 light-minutes. This distance is also called one *Astronomical unit* or 1 A.U. The diameter of the sun is 1.4×10^6 km. The mass of the sun is 2×10^{30} kg., the mean density is 1.4 g/cc and density at the centre is 110 g/cc. The surface temperature is 6000°C and the temperature at the centre is 20 million°C The sun is composed mainly of hydrogen, helium, oxygen, nitrogen, carbon, iron, magnesium, aluminium etc.

There are a number of dark spots on the surface of the sun known as sunspots (figure 1.4). They are comparatively cooler than the surrounding area. That is why they look dark. The spots vary in size. Their diameters vary from 32,000 km. to 160,000 km. The observation of the spots has revealed that the sun rotates on an axis. By observing the movement of the sun spots Galileo found the period of rotation of the sun to be 27 days. This observation was made around the year 1610. Present observation of the period of rotation is, however, 25 days.

1.9 The Solar System

The solar family contains nine planets moving round the sun in their respective elliptic orbits

(figure 1.5) They are in the order of their distances from the sun—Mercury (0.39 A.U), Venus (0.72 A.U.), Earth (1.0 A.U), Mars (1 52 A.U.), Jupiter (5.2 A.U.),

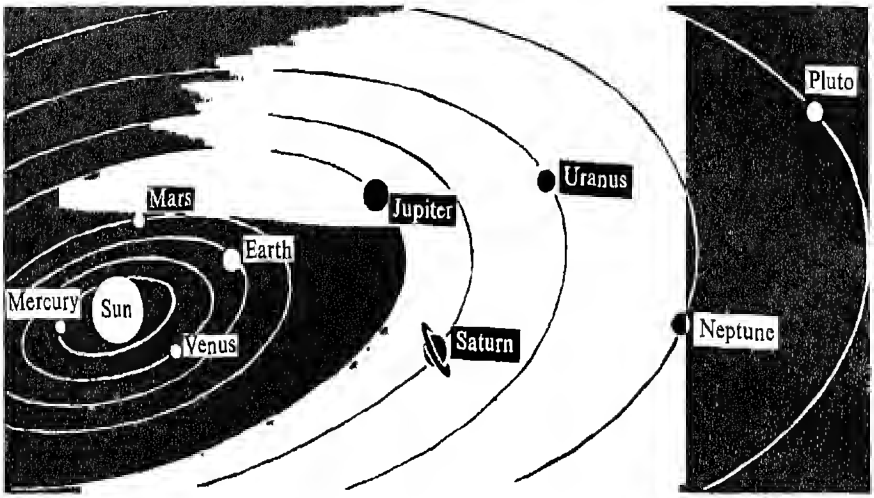


Fig. 1 5

Saturn (9.55 A.U.), Uranus (19.2 A.U.), Neptune (30.1 A.U.), and Pluto (39.6 A.U.).

Between Mars and Jupiter a large number of minor planets called *Asteroids* move round the sun, in their respective orbits. So far about 2000 minor planets have been catalogued. The biggest one is *Ceres* whose diameter is about 700 km. and the smallest one has a diameter not more that 3.2 km. Many of them do not have regular shapes and are huge blocks of materials with angular faces. The important of them are known as *Ceres*, *Pallas*, *Vesta*, *Juno*, *Hygeia* etc.

Some interesting informations about the planets are listed in Table 1,

Name of the Planet	Mean distance from the sun in millions of km	Mass compared to earth	Atmosphere present?	Diameter in km	Period of revolution round the sun in years	Period of rotation about its axis	Surface temperature	Surface gravity compared to earth	No of satellites
Mercury [1]	57 6	0 0470	No	4640 0	0.241 (88d)	88d	Towards the sun 410°C The other half ≈ —272.8°C	0 30	Nil
Venus*	107 5	0 8260	Yes Contains O_2, huge quantity of CO_2 and water-vapour	12320 0	0 615	30 0h	≈ 300°C	0 90	Nil
Earth	148 6	1 0000	Yes Contains O_2, N_2, Ar, CO_2, H_2 and water-vapour	12756 3	1 000	24 0h	15°C	1 00	1
Mars*	226 4	0 1080	Yes very thin Contains O_2, large amount of CO_2, and water-vapour	6744 0	1 880	24 6h	—38°C	0.38	2
Asteroids	416 2	0 0003	—	—	4.690	—	—	—	—
Jupiter [2]	773 3	318.4000	Yes. Contains NH_3, H_2 and CH_4	57120 0	11 860	9 9h	—138°C	2 65	12
Saturn [3]	1417 8	95 2000	Yes Contains NH_3, CH_4	114400 0	29 460	10 2h	—153°C	1 14	9+3 rings
Uranus [4]	2852 8	14 6000	Yes Only CH_4	51200 0	84 010	10 7h (?)	Below —184 4°C	0 96	5
Neptune [5]	4468 8	17 3000	Yes Only CH_4	443200 0	164 790	15 8h	Below —178 8°C	1 10	2
Pluto [6]	5872 0	0 1000 (?)	Not definitely known	5760 0 (?)	247.700	(?)	Below —212°C	(?)	Nil

(1) Since the period of revolution around the sun and the period of rotation about its own axis are both 88 days for Mercury, only one hemisphere always faces the sun The temperature on this hemisphere is 410°C and that on the other is—272 8°C

(2) (a) The four brighter satellites of Jupiter were discovered by Galileo in 1610

(b) Jupiter has a magnetic field and emits radio signals

(3) 1st ring diameter 2,74,400 km width 16,000 km and thickness 16 km
2nd ring diameter 2,32,000 km width 25,600 km and thickness 16 km
3rd ring diameter 2,03.200 km width 18,400 km and thickness 16 km

(4) Discovered by W Herschel in England on March 13, 1781

(5) Discovered by J G. Galle at Berlin on September 23, 1846

(6) Discovered by C W Tombaugh at Lowell Observatory on January 23, 1930.

* Inter-planetary rockets equipped with various instruments have reached Mars and Venus and have supplied valuable informations on the physical & chemical nature of the environment of these planets.

1.10 Other Members of the Solar System

Apart from the planets and their satellites, there are other members of the solar system. These are *meteors* and *comets*. They play a very insignificant part in the solar system. The meteors are small pieces of matter which travel in the interplanetary space more or less haphazardly. Whenever these bodies come in contact with the earth's atmosphere, they heat up due to friction and in most cases burn to ashes. During the process of heating, they glow up and look like shooting stars which you all may have noticed while gazing at the night sky. Sometimes a meteor will be large enough to be pulled down to the earth by the earth's gravity

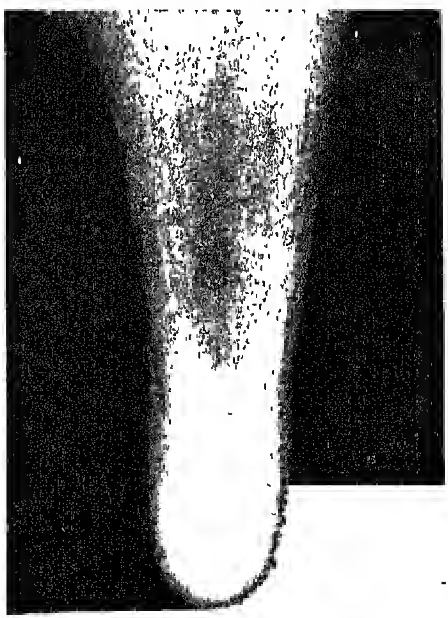


Fig 1.6

before it burns completely. The remnant of the material that reaches the earth's surface is called *meteorite*. Some of these meteorites can be seen in the museums.

A comet is a strange member of the solar system. Large pieces of material moving in the solar system are attracted by the sun's and also by the Jupiter's gravity and move in a parabolic, elliptic or hyperbolic path. Comets present a very magnificent sight. A molten and glowing mass, called the head of the comet, is followed by a long tail. The tail is always away from the sun. So far about 100 comets have been discovered. The famous "Halley's comet", (figure 1.6) was seen by Edmund Halley in 1759. It has a period of 76 years. It was last seen in 1910 and will be seen again in 1986.

1.11 The Moon

You are now well acquainted with the natural satellite of our earth which is the nearest heavenly body where man has set his foot. There are now large scientific data available on the physical, chemical and geological properties of the moon matter. Some basic informations of the moon are given below:

Mean diameter ..	3476 km.
Mean distance from the earth	384400 km.
Mass ...	7.351×10^{22} kg.
Period of revolution round the earth ...	27d 7h 43 m 11.5s (27.32d)
Period of rotation * about its own axis ...	27.32d
Temperature of the surface facing the sun ..	127°C

* Period of rotation about its own axis is equal to the period of revolution round the earth. As a result of this, the same face of the moon is always turned towards the earth.

Temperature of the other side		—153°C
Surface gravity	...	1/6 *g*. (*g*=value of acceleration due to gravity on the earth)

It is known for a long time that the moon has no atmosphere. This has been confirmed by unmanned moonflights of rockets which carried instruments to measure various physical properties. The invisible hemisphere of the moon has also been reached and studied with the help of rockets.

The surface of the moon visible to us has been the subject of study by many astronomers over several years. The first interesting study was, however, made by Galileo who used a small telescope to look into the lunar surface. Even with the naked eye you can see large grey patches on the moon. With the use of telescopes the moon surface looks very rough (figure 1.7). There are

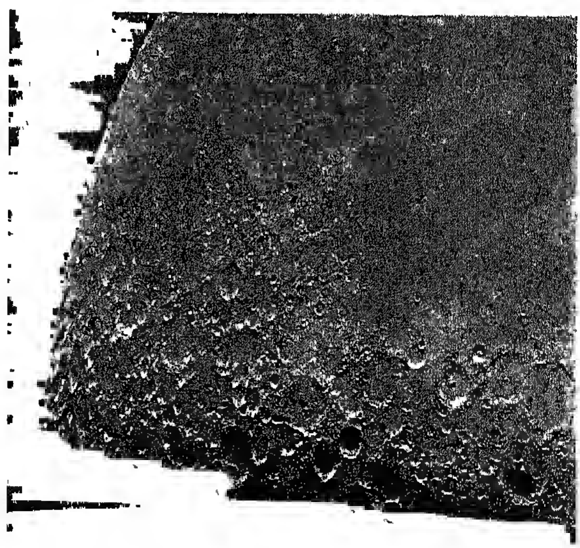


Fig 1 7

large mountains and big craters. The early astronomers had even tried to estimate the height of the moon mountains by looking at the shadows cast by the sunlight. Since the craters are seen like seabeds they are called 'Maria' (latin for 'seas'), and moon maps were prepared giving names to these 'seas'. The craters are ring like formations and resemble volcanic craters. Diameters

Fig 1.8

of some of these are as large as 211 km. and the height of the side-walls can be as high as 6108m. These are no longer speculations since men have walked on the moon's surface for many hours. You all know that Neil Armstrong and Edwin Aldrin landed on the surface of the moon on July 21, 1969 at 0826 hrs, I.S.T. in the *sea of Tranquility* (figure 1.8). The moon trip has been repeated since then.

You all know that moon has no light of its own It reflects the sunlight that falls on its surface. Only the lighted part is visible to us. You must have noticed that the lighted portion of the moon varies in size from day to day When the full disc is lighted we call it a *full-moon* and the night it is completely dark is called the

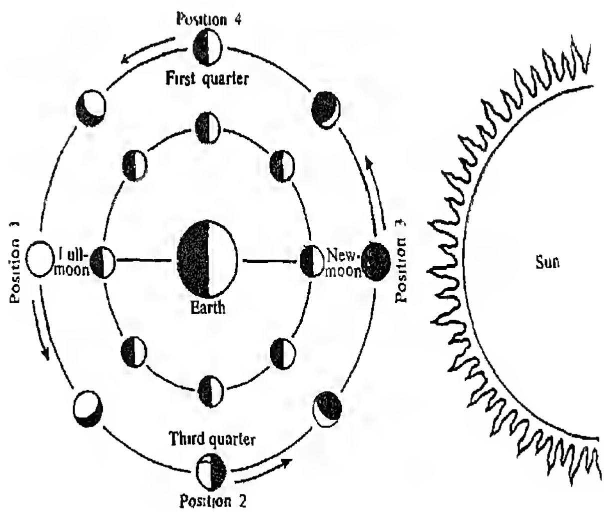


Fig 1 9

new-moon. You all know that each day is known as the phase of the moon. The reason why the moon has

phases is well-known. On a full-moon night, (position 1, figure 1.9), the moon is opposite to the sun and the earth lies between them. On that night you see the total surface of the moon which reflects light and appears as a bright disc. After a fortnight, on the new-moon day the moon lies between the earth and the sun (position 3) and its dark side faces the earth during day time. On that day the moon rises along with the sun, remains invisible during the day and sets along with the sun. This is why the moon is totally absent on a new-moon night. Next day it appears as a thin crescent low on the western sky at sunset. After that the size of the cresent of the moon increases day by day as it moves eastward till it becomes a half-circle. This is called a 'quarter' moon and can be seen in position 4 of the figure. After 'quarter', the size goes on increasing till it becomes full within a week. After full-moon the pattern is reversed. The moon slims down everyday, becomes 'quarter' within a week (position 2 of the figure) and totally disappears again after a week on the next new-moon night. In this way the cycle repeats.

You must have noticed that the time of rising or the setting of the moon recedes everyday by approximately one hour. This is due to the rotation of the moon round the earth

You have already read how an eclipse occurs. You should expect lunar eclipse on every full-moon night and a solar eclipse on every new-moon day. But do they really occur? No, they do not occur because the plane of the moon's orbit is inclined at 5° with that of the earth's orbit round the sun.

1.12 Hindu Astronomy

In India, the science of astronomy was cultivated from very ancient times. Even from the Vedic times i.e. about 3,000 B.C., the Indian savants were skygazers like the Egyptians and Babylonians. They divided the moon's path (lunar zodiac) in the sky into 27 parts each in the name of a star or star group contained in that division (Nakshatra). Apart from the stars in the lunar mansions like Asvini, Bharani etc., they recognised some other stars and constellations also like Agastya (Canopus), Lubdhaka (Sirius), Dhruba (Polaris) and Saptarsimandal (The Great Bear), Kalapurusamandal (The Orion), etc. They divided the year into 12 lunar months (sometimes an additional month was taken) and counted the months by the moon's nakshatra on the full-moon day. The months, however, started from new-moon in some systems and from full-moon in the others. In the 14th century B. C., the Vedic astronomers framed a perfect luni-solar calendar for a five-yearly period with 62 lunar months of which 2 were additional months. Their year was seasonal which started either from winter or from the middle of Indian spring.

From the 4th century A.D., Indian astronomy took a scientific turn and great developments came with the rise of Aryabhata, Varahamihira and Brahmagupta. They started the calculations from the vernal equinox and recognised the 12 signs of the *zodiac* like *Aries* (*Mesha*), *Taurus* (*Vrishava*), etc. and divided the year into 12 solar months according to the sun's motion through these signs. The seven week days named after

the sun, moon and five planets Mercury to Saturn was already in vogue before this time.

The Indian astronomers determined the length of the sidereal year or sun's annual motion through the stars as 365.25876 days (correct value 365.25636). The periods of the moon and of all the planets were also determined. That the earth rotates about its axis in 24 hours was known to them and the diameter of the earth (8,000 miles) was also determined. Like the Greeks and Babylonians they had the geocentric conception of the universe i.e. the sun, moon and planets move around the earth, the planets Mercury and Venus being bound to the sun. They recognised the nodes (points of intersection of the orbit of the moon with the plane of earth's orbit) of the moon's orbit and called them Rahu and Ketu which were otherwise also known as planets. The periods of revolution of these nodes were determined and these were utilised in eclipse calculation. The Hindu astronomers were marvellously successful in determining the length of the lunar month (29.53059 days). They devised very correctly the method of eclipse calculation. The relative distances of the planets from the sun were also determined by them with approximate results. The positions of all the stars named by them were determined by different astronomers at their respective times.

The most notable book on astronomy is the Surya-siddhanta written by an unknown astronomer who introduced refinements in the original Surya-siddhanta of Varahamihira of 6th century A.D. The last of the galaxy of early Indian astronomers is Bhaskaracharya of 12th century A.D. who wrote Siddhanta Siromani (Ganitadhyaya and Goladhyaya), an excellent treatise on astronomy.

When an object completes one revolution, the distance covered will be the circumference of the circular path. It will be equal to $2\pi r$. The time taken to complete one revolution is called the *period of rotation*, and is denoted by T. You also know that,

$$\text{Speed} = \frac{\text{Distance traversed}}{\text{Time taken}}$$

If v is the speed of rotation, then

$$v = \frac{2\pi r}{T}.$$

The number of rotations of an object in one second is called its *frequency* of rotation. This is usually represented by the symbol 'f'. From the definition

$$f = \frac{1}{T}.$$

$$\text{or} \quad fT = 1.$$

$$\text{Therefore,} \quad v = \frac{2\pi r}{T}$$

$$= 2\pi rf.$$

Exercises

(1) The turn table of a phonograph makes 100 revolutions in 2 minutes. Find out its period and also the frequency.

(2) If the minute hand of an ordinary clock has a length of 5 0 cm, find out the period, frequency and the speed of the tip of the minute hand.

(3) If the blade of a ceiling fan has a length of 60 cm and makes 3 revolutions/s, find the frequency and the speed of the tip of the blade

(4) A cycle wheel makes 100 revolutions in 1 minute, find out its period and also the frequency.

(5) A motor car wheel has a radius of 30 cm and makes 100 revolutions in 1 minute. Find the period, frequency and the speed of the car.

2.3 Radian

In the above expression for speed, you find a factor of 2π occurring on the right hand side. In practice the equation becomes much simpler if another unit is introduced for the angle. This is called *radian*.

Draw a circle of any radius, say r. From its circumference mark an arc AB of length equal to the radius of the circle as shown in figure 2.5. The angle AOB which this arc makes at the centre is called one radian. Measure the angle AOB with the help of a protractor. Can you now tell how many degrees make one radian? Cut another arc BC along the circumference equal to the radius r. Measure the angle COB.

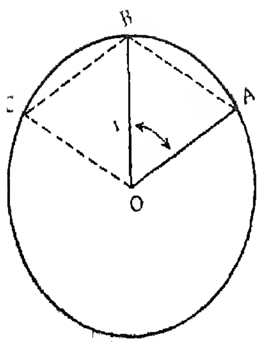


Fig. 2.5

Question

Can you tell how many radians the arc AC will make when $AC = 2r$?

Cut many arcs on the circumference till you cross the starting point A. Since every arc makes one radian, can you now tell how many radians a circle will subtend at the centre? You will see that this is not a whole number. Since a circle has a circumference of $2\pi r$, it is clear that a circle will subtend 2π radians at the centre.

Exercises

(1) A cyclist has a speed of 10 km/h. If the radius of the bicycle wheel is 50 cm, how many revolutions does the wheel make per second? What is the frequency of rotation of the wheel? What is the periodic time?

neither moves in the circular path nor does it fall vertically downwards but flies off in a straight line immediately as soon as the string is broken. The motion of the stone is shown in figure 2.1. From the figure you will find that the straight line representing the motion of the stone when the string is cut, meets the circular path at only one point. Such a straight line is called the tangent to the circular path and so you can say that the stone flies off tangentially

(2) Take an electric motor (provided in the kit) and clamp it in such a way that the axle is held in vertical position as shown in figure 2.2.

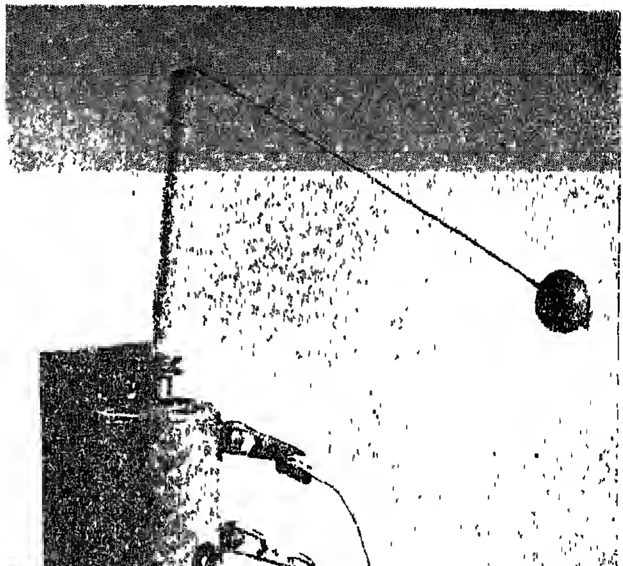


Fig. 2.2

Now take a piece of sewing thread, attach a stone to one end and fix the other end by, say, gum on the top of the axle. Start the motor. Watch what happens to the stone. Does the stone move in a circular path? Now light a candle and burn the thread at some intermediate point when the stone is in motion. What happens to the stone? Does it fly off in a straight line? What does this suggest?

(3) Take a piece of cloth and punch two holes at the two opposite ends (figure 2 3). Tie two strings about a metre long at the two holes. Place a stone on the cloth piece and fold it. Now hold both the strings firmly in hand. Whirl the stone overhead. Release one of the strings while keeping the other firmly in hand What happens to the stone? This is known as a sling used by farmers to fly away birds in fields.

Fig. 2 3

Question

How are the mud particles sticking to a bicycle wheel thrown off, when a few rapid rotations are given to the wheel?

2.2 Motion in a Circle with Uniform Speed

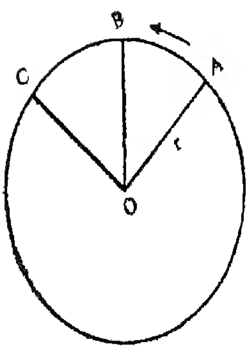


Fig 2 4

Consider an object moving in a circle of radius r. Let its position at any particular instant be A as shown in figure 2.4. Let the body move to the position B, say after 5 seconds. After another 5 seconds suppose the body is at C. If the distance AB is equal to the distance BC, then you can say that the speed is constant. Here, in equal intervals of time, equal curved paths are traversed. This is called *uniform circular motion.*

In table II and III you will get distances of some of the stars and galaxies from the earth.

Table II

Name of the star		Constellation to which the star belongs		Distance in light years
English name	Indian name	English name of the constellation	Indian name of the constellation	
1 α-Centauri	Prathama Kinnar	Centauri	Mahishàsur	4.20
2 Sirius	Lubdhak	Canis Major		8.70
3. Procyon	Prashwà	Canis Minor		11.40
4 Altair	Srabanà	Aquila		16.40
5 Vega	Abhijit	Lyra	Veenà	26.40
6 Pollux (β-Gemini)	Vishnu Tàrà	Gemini	Mithuna	34.80
7. Arcturus	Svati	Botis		35.86
8 Capella	Brahma Hriday	Auriga		45.64
9 Polestar	Dhrubatàrà	Ursa Minor	Laghu saptarshi Mandal	47.00
10. Aldebaran	Rohini	Taurus	Vrishava	68.46
11 Regulus	Maghà	Leo	Simha	84.76
12. Spica	Chitra	Virgo	Kanyà	211.90
13. Antares	Jyesthà	Scorpion	Vrischika	423.80
14 Betelgeuse (α-orion)	Adrà	Orion	Kalpurusha	586.00
15 Deneb	Prathama Hamsa	Cygnus	Hamsa	1630.00

Table III

Name of the galaxy	Distance from the earth in km	Distance from the earth in light years
1 Milky way (in which our sun is one of the 3×10^{10} stars Its diameter is about 100,000 light years)	6.20×10^{17}	6.20×10^{4}
2. Andromeda	8.50×10^{18}	8.50×10^{5}
3. Ursa Major	9.46×10^{18}	9.46×10^{5}
4 Cygnus A	16.08×10^{19}	16.08×10^{6}

2 CIRCULAR MOTION

2.1 Introduction

In everyday life you see cars, cycles, carts, buses and trains, etc. moving on wheels which are circular in shape. Sometimes these wheels are large and sometimes they are small. All the wheels move about an axis. If you happen to live in a village you may have seen a 'Charkha' or a potter's wheel. These wheels are different from the previous ones in one respect. They are confined to a place.

Try to understand some aspects connected with circular motion. The motion of a wheel is an example of *circular motion*.

Activity

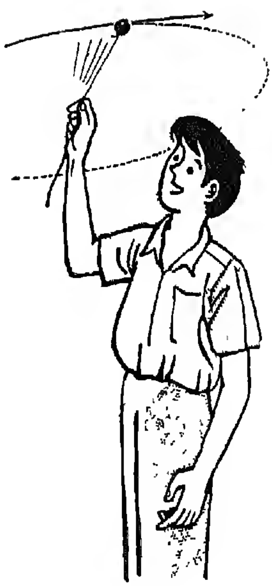


Fig. 2.1

(1) Take a piece of stone and tie it to one end of a string. Hold the other end of the string firmly in your hand and whirl it over your head. What do you find? You will find that the stone moves in a circular path and the string, that you are holding in your hand is fully stretched and the hand experiences a pull. In order that the stone keeps on rotating you have to pull the string inwards. Repeat the experiment, but this time whirl the stone faster. What do you observe? You will feel a greater pull on your hand, which means that you have to pull the string harder. If by chance the string breaks, what do you expect to happen? Should the stone continue to move in a circular path? If not, should it fall immediately to the ground? You will find that the stone

(2) A motor is speeding at 30 km/h. Determine the frequency and time of rotation of the wheels when each wheel has a radius of 40 cm.

(3) A scooter wheel has a radius of 20 cm. It makes 4 revolutions per second. What will be its frequency? What will be the speed of the scooter?

2.4 Angular Velocity

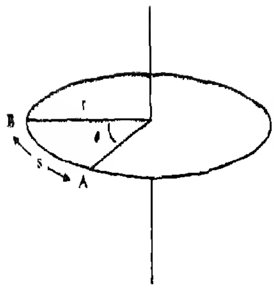


Fig 2.6

Suppose you have a wheel of radius r and a point A marked on its rim (figure 2.6). Turn the wheel about its axis through some angle say θ radians. The point A will move to a new position B, such that the arc AB = distance s. If θ is 1 radian s = r. If θ is 2 radians, then s = 2 r, and so on. In general, for θ radians, the distance s will be equal to $r\theta$. For 2π radians, the distance s will be the circumference of the circle itself, that is 2π r.

If the time taken to turn the wheel through an angle θ radians be t seconds, then the rate of turning will be θ/t radians per second. This is called the angular velocity and is represented by the symbol ω. Therefore you have

$$\omega = \frac{\theta}{t},$$

and the linear speed at A will be

$$v = \frac{r\theta}{t},$$

$$\text{or} \quad v = r\omega.$$

Find a relation between angular velocity and the frequency f. You know that $v = \frac{2\pi r}{T} = 2\pi rf$. Also $v = r\omega$.

Therefore, $r\omega = 2\pi\, rf$,

or $\omega = 2\pi f$.

2.5 Centripetal Force

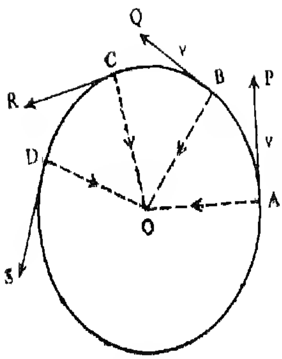


Fig 2.7

Consider a body moving along a circular path with uniform angular velocity. What is the direction of its motion at A, B, C, D etc. (figure 2.7)? Does the direction of motion continuously change? Does this involve an acceleration? The body had a speed v along AP when it was at A. When it has moved to B, its speed is again v but along BQ. If there was no acceleration on the body when at A, it would have moved along AP at the point A To bring the body to move along AB, you will have to pull it towards the centre O From the figure you see that the body tries to move along AP, BQ, CR and DS at the points A, B, C and D respectively. To be in the circular path, the body is pulled along AO, BO, CO and DO i.e. always towards the centre. Thus to keep the body moving along the circle, it has to be pulled continuously towards the centre.

In the case of a stone tied to a string and whirling overhead, it moves with a uniform circular motion so that its speed is constant. Its velocity, however, will not be constant. It will keep on changing its direction of motion continuously. The velocity, as you know, is a vector quantity. It has a magnitude as well as direction. So, although the magnitude of the velocity in a uniform circular motion remains the same, the change of direction implies a change in velocity. Since during the motion the velocity is changing, there is an acceleration. In this case the stone is accelerated. This acceleration is known as *centripetal acceleration*. The literal meaning of the word "centripetal" is "directed towards the centre". If now the string breaks, what happens? You will find that the stone flies off in a straight line. What will be its velocity? You can readily say that the stone will

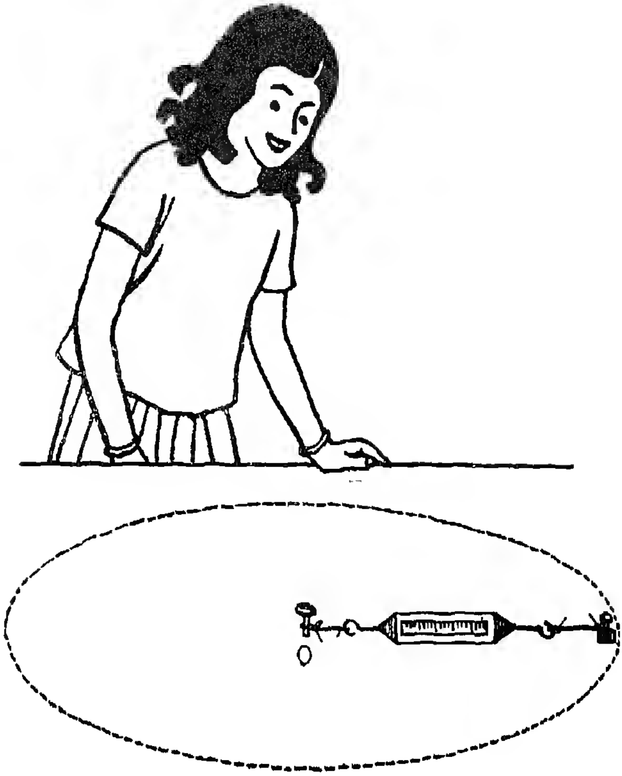


Fig 2.10

transmitted through the string is exerted on the metal piece. Now instead of 50g mass, keep 100g mass and rotate the disc again. Where does the pointer move now? Has it moved farther from the previous case? If so, does it mean that the pull exerted by the spring balance is proportional to the mass of the body? Now keep the length of the string and the mass of the metal piece same. Rotate the disc with different speeds. Take the readings of the spring balance You will find that the pull recorded by the spring balance will vary with the speed of the metal piece.

Question

If you double the speed of rotation how many times you have to increase the pulling force?

Next, keep the same metal piece on the disc, but now change the length of the string. The speed of course has to be kept the same. Rotate the disc and observe the position of the pointer of the spring balance for different lengths. What do you find? From the movement of the pointer can you find any relation between the force and the length of the string?

If you now combine all the observations you can say that,

$$F = mr\omega^2.$$

2.7 Centrifugal Reaction

You have seen earlier that when you whirl a stone overhead, your finger has to pull the string inwards. An equal and opposite force acts on the hand. This is known as the *centrifugal reaction.* 'Centrifugal' means acting away from the centre. As you whirl the stone faster and faster, the centrifugal force on the hand acting through the string also becomes stronger. Finally a stage comes when the string can not withstand this large force and the string breaks. The body then flies off in a straight line.

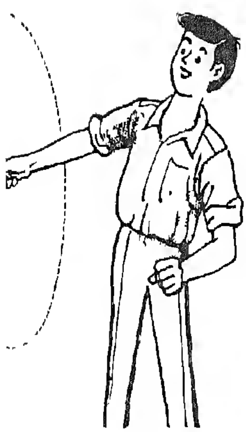


Fig. 2.11

Activity

Take a small plastic toy bucket. Put a small lump of dust or some quantity of water in the bucket and tie it with a stout piece of string. Hold the other end of this string in hand and whirl it in such a way that the bucket comes overhead with its mouth downwards once in every revolution as shown in figure 2.11.

Cancelling t^2 from both sides, you get

$$v^2 = aR,$$

$$\text{or} \quad a = v^2/R. \qquad (3)$$

This gives the magnitude of the centripetal acceleration. The centripetal force will, therefore, be

$$\begin{aligned} F &= \text{mass x acceleration} \\ &= m \times \frac{v^2}{R} \\ &= \frac{mv^2}{R} \\ &= mR\,\omega^2. \qquad (4) \end{aligned}$$

Activity

Take a hollow glass tube or a wooden reel of thread and a string (figure 2.9). Put this string in the glass tube. Tie a pan at the lower end of

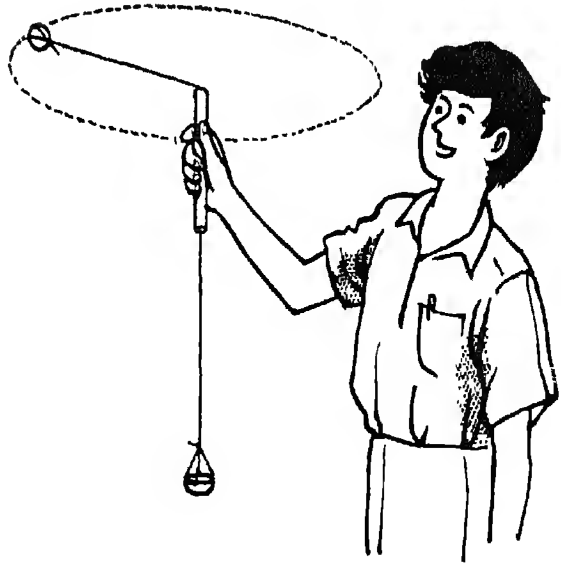


Fig. 2.9

this string and a stone at the upper end as shown in the figure. Put some weights on the pan. Hold the tube in your hand and rotate it.

What do you find? You will find that as you increase the speed of rotation, the string becomes taut and the pan tries to move up. As you move faster and faster, the stone tries to move farther away from the rim of the tube. This means that if you increase the speed of rotation there is an increase in the radius of the circle described by the stone than what it was when you were rotating the tube slowly. Thus as you move it faster, the radius changes.

Question

If your friend cuts the string near the pan while you rotate the stone in the open in the above experiment, what will happen?

Activity

Take a disc with a smooth surface and mount it in such a way that it can rotate about a vertical axis passing through the centre O. Place a metal piece of mass 50g at the rim of the disc and rotate it. What do you observe? You will find that the metal piece is thrown away. Why is it so? Does it mean that an inward pulling force is necessary to keep it moving in a circle? Now attach a hook to the vertical axis and tie a thread to it. Tie the other end of the thread to a spring balance (figure 2 10). Place the spring balance along the radius of the disc and attach the metal to its free end. Now rotate the disc. What do you find? You will find that the metal piece moves outward till the string is under tension. Read the spring balance. This shows that a pull being

have that velocity which it had at the instant the string broke. If the string does not break, then the stone can keep on moving in a circular path.

Whenever a body is accelerated, you know that it is due to a force. In a circular motion, since there is an acceleration, there must be a force causing this acceleration. When you whirl the stone in a circle, you are applying a force on the stone through the string. Thus the string exerts a force on the stone. Its direction will clearly be along the string. This means that the force acting through the string pulls the stone steadily towards the centre of the circle and makes it move in a circle. When this force vanishes, that is, when the string breaks or is released, the body flies off in a straight line direction. This force directed towards the centre, required to keep the stone moving in a circle, is called *centripetal force*.

The centripetal force may be gravitational in nature as in the case of satellites and the moon revolving round the earth. It may be electrical in nature as in the case of electrons revolving round positively charged nucleus of an atom.

2.6 Centripetal Acceleration

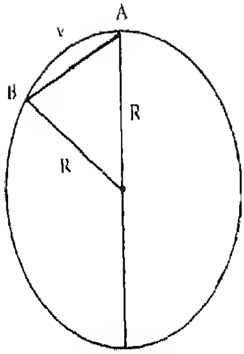


Fig. 2.8 (a)

Suppose a stone of mass m moves in a circular path with uniform speed v as shown in figure 2.8 (a). Let it start from the position A and go to the position B in a short interval of time t. Now as A moves towards B, there is a tendency on the part of the stone to fly off in a tangent, but it is prevented from doing so by the acceleration of the stone (due to a force) directed towards the centre. Therefore the circular arc AB as shown in figure 2.8 (b) can be regarded as a combination of

the motion along the tangent AC and the acceleration which is directed towards the centre. To follow the circular path, the stone must accelerate towards the centre through a distance h in the same time as required by it to move along a tangential distance AC = d (say). Since v is the speed, the distance covered in time t is

$$d = vt. \tag{1}$$

Let a be the acceleration, then in this time t (time taken to cover the horizontal distance) the stone will travel towards the centre a distance equal to h. Then from the equation

$$\begin{aligned} h &= vt+\tfrac{1}{2}\,at^2 \\ &= 0+\tfrac{1}{2}\,at^2 \\ &= \tfrac{1}{2}\,at^2. \end{aligned} \tag{2}$$

This is so because at $t = 0$, the speed of the stone towards the centre is zero.

Consider the figure once again. In $\triangle$ OAC, $\angle$ OAC $= 90°$

$$\begin{aligned} \therefore\ (OA)^2 + (AC)^2 &= (OC)^2 \\ \text{or} \qquad R^2+d^2 &= (R+h)^2 \\ &= R^2+2hR+h^2. \end{aligned}$$

R^2 terms cancel out from both sides and so you have

$$d^2 = 2h\,R+h^2.$$

This expression can be simplified further. The distance h will be quite small in comparison to R when the $\angle$AOC is small and so h^2 will be still smaller. You can, therefore, write

$$d^2 = 2hR$$

Substituting the values of 'd' and 'h' from the relations (1) and (2) you get

$$\begin{aligned} (vt)^2 &= 2R\,(\tfrac{1}{2}\,at^2) \\ \text{or} \quad v^2t^2 &= aRt^2. \end{aligned}$$

What do you observe? You find that the dust particles or water do not fall when the bucket is over your head with its mouth downwards. This is so because there is a balance between the centripetal force and the centrifugal force. The inward pull is applied through the rope, whereas an equal and opposite force acts on the hand. If this force were not present then the bucket would have moved towards the centre of the circular path and the rope would have slackened. But this does not happen and the bucket continues to move in a circular path at the same distance from the centre. This is due to the centrifugal force which is just equal and opposite to the centripetal force. If one of these forces become greater than the other, the circular motion ceases, the bucket with water either flies off in a straight line or is drawn towards the centre.

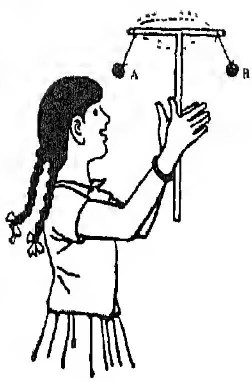


Fig 2.12

Activity

Take a wooden rod fixed with another rod perpendicular to it at the top. Two balls A and B are suspended with pieces of thread (figure 2.12). Rotate the vertical rod. What happens to the balls? If you increase the speed of rotation, do the balls move closer to the vertical rod or further away from it? Explain your observations.

You have seen a merry-go-round. It has two circular iron rings from which wooden horses are suspended alternately (figure 2.13). Suppose you occupy the position A on the outer circular ring and your friend the position B on the inner circular ring. What happens to you and to your friend when the merry-go-round is rotated? Which one of you is pushed away

more from the centre? If the speed increased appreciably, what do you and your friend experience?

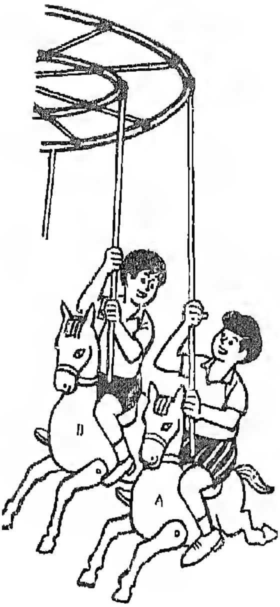


Fig. 2.13

2.8 Motion of planets round the sun

You know that various planets like Mercury, Venus, Earth, Mars, Jupiter, Saturn, etc. revolve round the sun. What keeps these planets revolving round the sun? Why do they not move away from or crash on the sun? The answer is quite simple. These planets are kept in orbit by the centripetal force and this force is provided by the gravitational attraction between these planets and the sun. If m be the mass of a planet, say earth, v its uniform speed and r the distance between the centres of the planet and the sun (figure 2.14), then the required centripetal force is

$$F=\frac{mv^2}{r}.$$

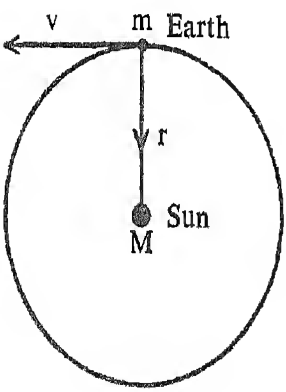


Fig. 2.14

But the gravitational force, that is attraction between the sun and the planet is given by

$$F=\frac{GmM}{r^2},$$

where M=mass of the sun and G is a universal constant called the *gravitational constant.*

Therefore, $$\frac{GmM}{r^2}=\frac{mv^2}{r},$$

or $$GM/r^2=v^2/r,$$

or $$v=\sqrt{\frac{GM}{r}}.$$

The period of rotation of the planet is

$$T=2\pi r/v.$$

Substituting the value of v, you get

$$T = \frac{2\pi r}{\sqrt{\frac{GM}{r}}}$$

$$= \frac{2\pi r^{\frac{3}{2}}}{\sqrt{GM}} .$$

Squaring both sides, you get

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3.$$

Since the quantity inside the bracket is constant, it follows that the square of the period is proportional to the cube of the radius of the circular orbit. This is one of the Kepler's laws of planetary motion.

Exercise

The times of revolution and the distances from the sun of different planets are given. Try to find the relationship between T^2 and r^3.

Planet	Radius r in astronomical* units	Time period T in years	r^3	T^2
Mercury	0.39	0.24		
Venus	0 72	0.61		
Earth	1.00	1.00		
Mars	1.52	1 88		
Jupiter	5.20	11.86		
Saturn	9.55	29.46		

*1 *Astronomical unit*=14 96×10[7] km.

2.9 Motion of the Moon round the Earth—Satellites

You know that the moon revolves round the earth almost in a circular orbit. A body that revolves round a planet is called a satellite. Therefore the moon is a satellite of the earth.

The centripetal force necessary to keep the moon in uniform motion along its circular orbit is provided by the gravitational attraction between the earth and the moon. If m be the mass of the moon, v its uniform speed and r the distance between the centres of the earth and the moon, then the period of the moon is given by

$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$ as shown earlier for a planet.

From the equation $v = \sqrt{GM/r}$, you can calculate the speed of a satellite, if you know its distance from the centre of the earth. Also note that this *orbital speed* of a satellite does not depend on its mass. It may be a heavy body like the moon or a smaller body like a *sputnik* or any other artificial satellite that has been launched.

Also from the equation $T^2=(4\pi^2/GM)\ r^3$, since quantities inside the bracket are constant, knowing the period, you can find the distance of the satellite from the earth.

Now find the speed of the moon in its orbit round the earth. You know the distance of the moon from the earth is $3{\cdot}84 \times 10^8$ m and mass of the earth is 6×10^{24} kg.

Applying the relation, $v = \sqrt{\frac{GM}{r}}$, where $G = 6{\cdot}67 \times 10^{-11}\ N\ m^2\ kg^{-2}$

you get

$$v = \sqrt{\frac{6{\cdot}67\times10^{-11}\times6\times10^{24}}{3{\cdot}84\times10^{8}}\ \frac{\text{Newton m}^2}{\text{kg}^2}\ \frac{\text{kg}}{\text{m}}},$$

$$= 1021\ \left(\frac{\text{N. m}}{\text{kg}}\right)^{\frac{1}{2}},$$

$$= 1021 \text{ m/s.}$$

This result can be arrived at in another way. Since moon takes 27·3 days to complete one revolution, you have

$$v = 2\pi r/T,$$

$$= \frac{2\pi\times3{\cdot}84\times10^{8}}{27{\cdot}3\times24\times3600}\ \text{m/s},$$

$$= 1022 \text{ m/s.}$$

This shows that you must know one of the quantities, either r or T, to find the speed of a satellite round the earth.

Exercises

(1) If the periodic time of a satellite is 94 minutes what should be the distance at which the satellite should move above the earth? (Radius of the earth is 6400 km).

(2) What should be the distance of a satellite from the surface of the earth so that its period of revolution is exactly 24 hours? (Hint: Use $T^2 = 4\pi^2 r^3/GM$. Subtract the radius of the earth 6400 km from the total distance).

(3) Try to find out the period of revolution of an artificial satellite of the earth at a height of 400 km above

the surface of the earth. (Given radius of earth 6400 km).

2.10 Motion of an electron inside an atom

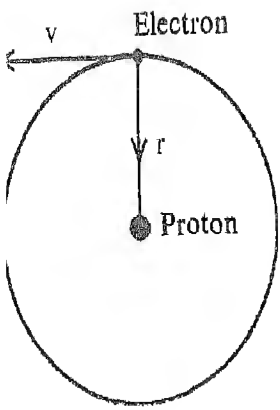


Fig. 2 15

You know that an electron in an atom revolves round the nucleus containing protons and neutrons in a manner similar to the earth's revolution round the sun. In an atom the centripetal force which keeps the electron revolving round the nucleus originates from the electrical attraction between the positively charged protons in the nucleus and the negatively charged electrons in the orbit (figure 2.15).

Now try to find out the centripetal force which keeps the electron in motion round the nucleus of an atom of hydrogen. Let m be the mass of the electron (10^{-28} g) and v its orbital speed, then the centripetal force is mv^2/r.

The electrostatic force of attraction between the proton and the electron separated by a distance r is

$$\frac{e\,.\,e}{r^2} = \frac{e^2}{r}\,.$$

Hence $$\frac{mv^2}{r} = \frac{e^2}{r^2},$$

or $$v^2 = \frac{e^2}{mr}.$$

The periodic time $T=2\pi r/v$. Thus you can find the speed as well as the periodic time of an electron revolving round the nucleus if e and m are known.

3 MOMENTUM

3.1 Introduction

You know that a force is necessary to set a body in motion. Similarly a force is also necessary to stop a moving body or change its uniform motion in a straight line. You use force to increase the speed of your bicycle and also apply force (brakes) to slow it down. When you are in a hurry, you pedal hard to increase the speed of your bicycle. When you want to stop suddenly, you apply both the brakes very hard.

Hit a marble, it goes a certain distance. If you hit it harder, it goes a longer distance. Again if you throw a cricket ball, it moves fast. But the same force can not move a shot-put ball so fast. Is there any relation between the impressed force and the mass and velocity of a moving body?

Activity

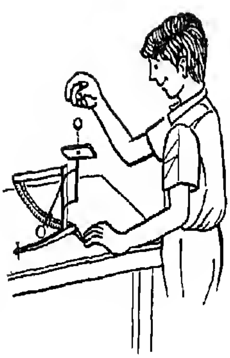


Fig 3.1

(1) Take a balance having a disc attached at the top of a rod and a pointer (provided in the kit) which moves over a graduated scale calibrated on the arc of a circle (figure 3.1). The pointer moves when the disc is pressed Keep some sand on the disc and sprinkle little water. ~~Now keep a 100g weight~~ on the sand. Note roughly the position of the pointer. Now take this 100g weight to a height of say 30 cm above the disc and release it. What happens to the pointer? Note roughly the deflection of the pointer. Next, instead of a 100g weight take a 200g weight and allow it to fall on the disc from the same height. Note the

deflection of the pointer. You will find that as the mass is increased the pointer is deflected more and more. Since the weights are falling from rest under gravity, you know that they strike the disc with the same velocity and differences in the pointer deflection arise from the differences of the masses of the weights. This means that as the mass is increased, the force with which the weight strikes the disc of the balance is also increased.

Now take the same 100g weight, but release it from different heights say 20 cm, 30 cm, 40 cm, etc. and observe the position of the pointer in each case. You will find that the weight released from greater height will deflect the pointer more. You know that as the height is increased, the velocity also increases. Thus as the velocity increases the force with which the weight strikes the disc is also increased.

(2) Take a wooden rod ABC about half a metre long, 2 cm thick and 2 cm in breadth. Drill a hole at B at a distance of say 10 cm from the end C. Pass a nail through the hole and support it on two wooden grooves such that the rod can move freely about the nail shown in figure 3.2. Since the nail is fixed near the end, the rod is unbalanced. In order that the rod remains horizontal attach a hook to its lower face near C and another hook on the table and hold the rod in position by means of a rubber band or a spring. Fix a small pan at the end A and a pointer at the end C which can move over a scale as shown in the figure.

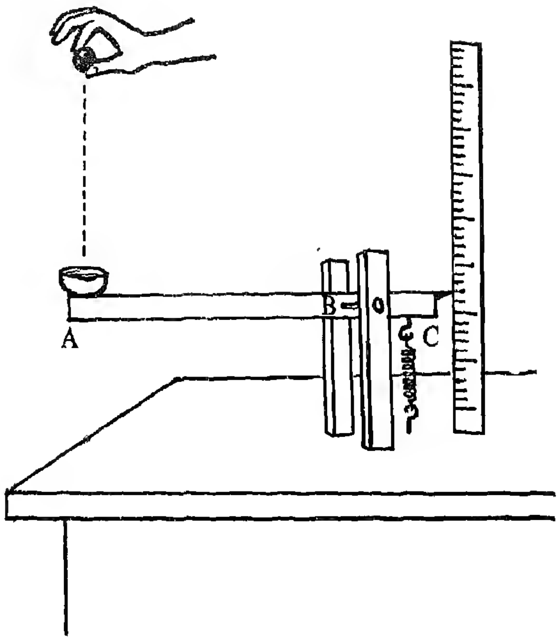


Fig. 3 2

Now take a marble and drop it on the pan at A (which is half filled with sand) from a height say 25 cm. Next, drop the same marble from 50 cm, 1 m, 1 5 m, etc Observe the change in the position of the pointer on the scale. What can you conclude from this change? Next take marbles of different masses and release them from the same height on the pan at A. Do you find any change in the position of the pointer for each fall of the marble? What does this suggest?

From the above experiments you find that the force which has deflected the pointer off balance depends on mass and velocity. The effect produced by a moving

body, therefore, depends on its mass and velocity. This effect is due to the combined action of mass and velocity. This combination is termed as the quantity of motion or the *momentum* of a moving body The momentum is measured by the product of mass and velocity

momentum=mass x velocity.

Activity

(1) Construct an inclined plane with a board and some blocks of wood or books as shown in figure 3.3. The board should have two grooves cut along its length so that a trolley

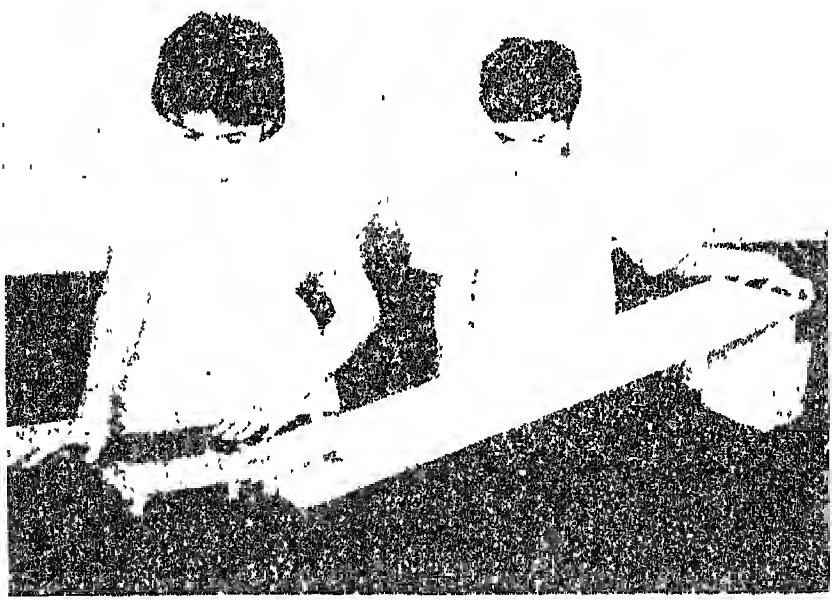


Fig 3 3

can pass along the grooves. Take two identical trolleys A and B (provided in the kit). Ensure that the end of the plane where it touches

the table is continuous so that the trolley does not jump as it passes from the plane to the table. Place trolley A on the table at the end of the ramp. Take trolley B to the top of the inclined board and then release it along the grooves. Trolley B strikes trolley A at the bottom of the ramp and forces it to move a certain distance. Measure this distance. Repeat this several times and find the average distance travelled by trolley A. Next tie a geometry box to trolley A and release trolley B again from the same height. Find the distance moved by trolley A and the geometry box. Repeat the experiment a number of times and find the average distance moved by the combination of the geometry box and trolley A. Now keep a diary and the geometry box on trolley A and release trolley B again from the same point at the top of the board. Find the distance moved by the combination of trolley A. Repeat the experiment a number of times. Do you find any difference in the three sets of observations? You will find that greater the combined mass of trolley A and the articles placed on it, smaller the distance the combination will move.

(2) Construct an inclined plane with the board and some books or blocks as before. Place trolley A on the table at the end of the ramp. Tie a geometry box to trolley B with a thread and release this trolley from the top of the inclined board (figure 3.4). What do you find? You will find that trolley B strikes trolley A at the bottom of the ramp and forces

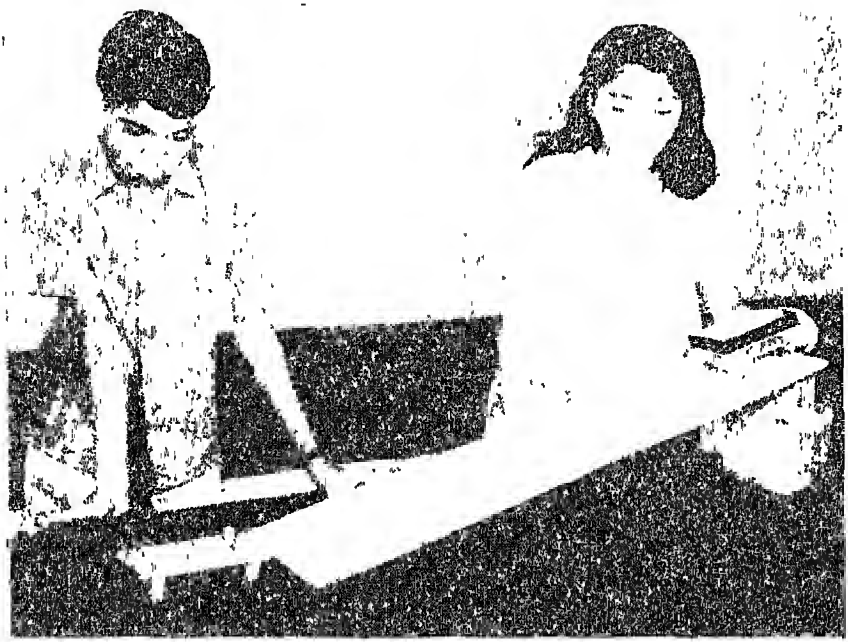


Fig. 3 4

it to move a certain distance. Measure this distance. Repeat the experiment several times and take the average distance. Next replace the geometry box tied to trolley B by a note-book of the same size but of less mass. Release trolley B from the same position again and find the distance trolley A is pushed from the bottom of the ramp. Compare the distances travelled by trolley A in the two cases. You will notice that trolley A travels a greater distance when hit by trolley B carrying the geometry box than when it carries the note-book. This means that the increased mass of the striking trolley B travelling with the same velocity causes trolley A to travel a

larger distance. Repeat this experiment with different bodies on trolley B and note the results

(3) Now do this experiment in another way. Place one end of the board on some books or blocks to form an inclined plane as shown in figure 3 5 Release trolley B from the top of

Fig 3 5

the inclined plane and let it hit trolley A as before. Note the distance up to which trolley A travels. Now change the inclination of the plane by changing the height of the books or blocks placed under the end of the board as shown in figure 3.6. Release trolley B again. Note the distance up to

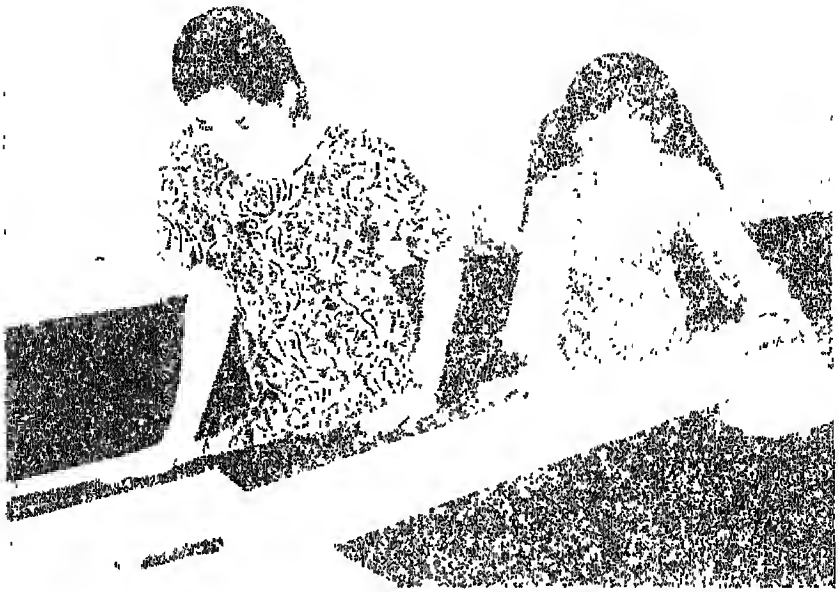


Fig 3.6

which trolley A moves now. Is there any difference in the two readings? You will find that on account of increased velocity with increased inclination the same mass causes trolley A to move a larger distance.

Now try to understand the results of the above experiments. When trolley B strikes trolley A with a definite velocity, the latter starts to move with a velocity v as a result of collision. This collision lasts for a short time, say t. The motion of trolley B decreases due to collision and it ultimately comes to rest. On the other hand the force acting on trolley A of mass m due to the collision generates an acceleration 'a' in it. The magnitude of the velocity with which a trolley moves under the action of a force F depends on how long it acts on the trolley. But F is equal to $m \times a$. The moving

body continues to be accelerated so long as the force acts on it. The force acts, say, for t seconds. Trolley A was initially at rest and because of this acceleration it started moving. If the velocity of trolley A after collision with trolley B is v, then

$$v = 0 + at.$$

$$\text{Now} \quad F.\,t = m.a.t.$$
$$= mv.$$

The quantity $F \times t$ which appears in the above equation is called the *impulse* of the force and the quantity $m \times v$ is the momentum of the trolley travelling with speed v. This equation tells you that an impulse of magnitude Ft is required for a body of mass m to acquire a momentum mv, such that $Ft = mv$.

Thus in the above experiments you find that to start trolley A moving, you have to apply some initial push or force. The motion of the trolley depends not only on the amount of push given, but also upon the time for which the push acts and the mass of the trolley. The magnitude of the impulse of the force on the trolley is equal to the product of the mass of the trolley and the velocity acquired by it after the collision. Thus greater the impulse, greater is the momentum gained. Conversely greater the momentum of a moving object, greater the force needed to stop it in a certain time. Thus you have:

(1) Larger the mass of an object moving with a certain velocity, greater is the force which is required to stop it in a given time.

(2) Higher the velocity of a moving object having a

certain mass, greater is the force which is required to stop it in a given time.

(3) Larger the mass of an object at rest, greater is the force required to move it in a given time with the same velocity.

(4) An object with a certain mass, initially at rest, will require a greater force to attain a higher speed within a given time.

Activity

Place a trolley on a table. Let a pan be attached to the trolley with a piece of string passing over a pulley. Fix a water timer to a stand on the table as shown in figure 3.7. Hold

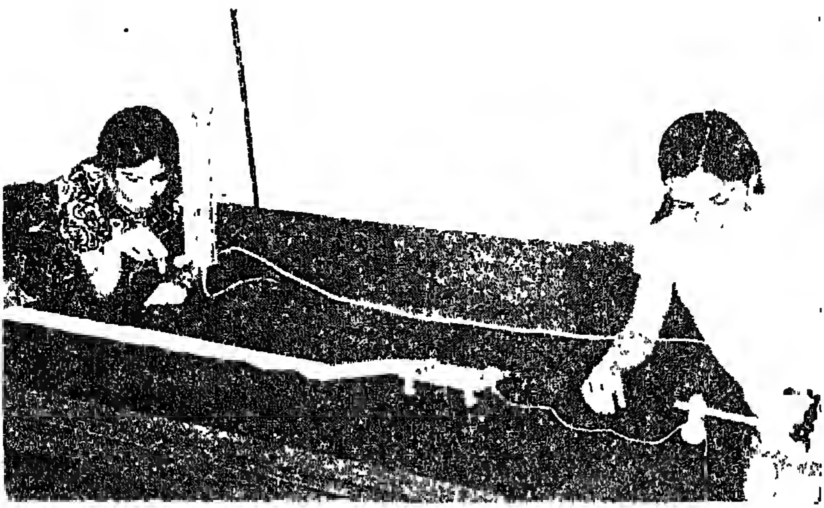


Fig. 3.7

the pan in hand at a height of 20 cm above the floor. Place a weight of 20 g on the pan.

Release the pan. The trolley begins to move and the pan falls to the ground. Note down the time required for the pan to fall to the ground. Raise the pan again to the height of 20 cm as before with a weight of 20 g on it. Release the pan and start the water-timer. Examine the impressions made by the water droplets on a paper roll trailing behind the trolley. Are these droplets equidistant all over the paper roll? Do you find that they are equidistant after a few drops? Can you make out from the paper that the drops are equidistant after the pan touches the ground? Measure the velocity of the trolley from these equidistant drops. If m is the mass of the trolley, the momentum imparted to the trolley by the falling weight on the pan is m × velocity that you have measured. The force acting on the trolley is $(m'+0.02)\,g$, where m' is the mass of the pan in kilograms and $g = 9.8\ m/s^2$. Convert the force into newtons and record in your table. You have assumed in this case that friction at the pulley for the motion of the trolley is negligible. The time for which this force acts is the time required for the pan to fall on the ground. You can change the force acting on the trolley by putting different weights on the pan. You can also change the time for which the force acts by allowing the pan to fall from different heights. You can change the mass of the moving system by placing different weights on the trolley. Measure the velocity of the trolley generated by the force acting on the trolley in each case and tabulate your results.

Observation	F in N	t in s	m in kg	v in m/s	F.t	m.v
1						
2						
3						
4						

Do you get F t = m.v from the above observations?

Questions

(1) *A massive vehicle causes more damage to an obstacle on its path after a collision than a lighter vehicle moving with the same velocity—explain.*

(2) *A man wishing to break a piece of rock uses a sledge hammer rather than a small hammer of less mass. Why?*

(3) *A heavy stone is more dangerous than a lighter one when they fall from the same height. Explain why?*

(4) *A faster blow with a hammer causes a nail to penetrate deeper than a slower tap with the same hammer. Why?*

(5) *In a game of cricket, while catching a fast moving ball, the player allows his hands to go a little along with the ball. Why does the player do so?*

3.2 Change of Momentum

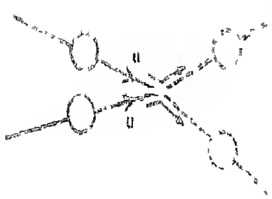


Fig 3.8

When a ball moving with a velocity u strikes another ball moving with the same speed, but in a different direction they will move in different directions after the collision (figure 3.8). The new velocities of the balls are different from their initial velocities. Now try to understand why this happens. The force due to impact between the balls gives rise to an acceleration 'a' in one of the balls. Now express the final velocity v and the initial velocity u of this ball in the following way. Assume for convenience that v and u are in the same direction then from the equation you read earlier

$$F \times t = mv - mu.$$

This means that the impulse of a force is equal to the change of momentum which the force produces. The ball had initial momentum mu and final momentum mv so that the change of momentum is mv – mu.

Therefore, *the net force = rate of change of momentum*. In the same way you can prove that this is true for the second ball.

3.3 Momentum is a Vector

Momentum, as you have seen, is the product of mass and velocity. Now mass is a scalar quantity and velocity a vector quantity. The product of a scalar and a vector quantity is also a vector quantity. Thus momentum is a vector quantity and has direction as well as magnitude.

3.4 Conservation of Momentum

Activity

Take two trolleys of the same mass and place them on a smooth table or glass plate. See that one of them is provided with a spring. Press the trolleys together so that the spring is compressed and hold them in position with a thread (figure 3.9). Suddenly cut or burn the thread. What do you observe? What is the force that acts on both the trolleys and pushes

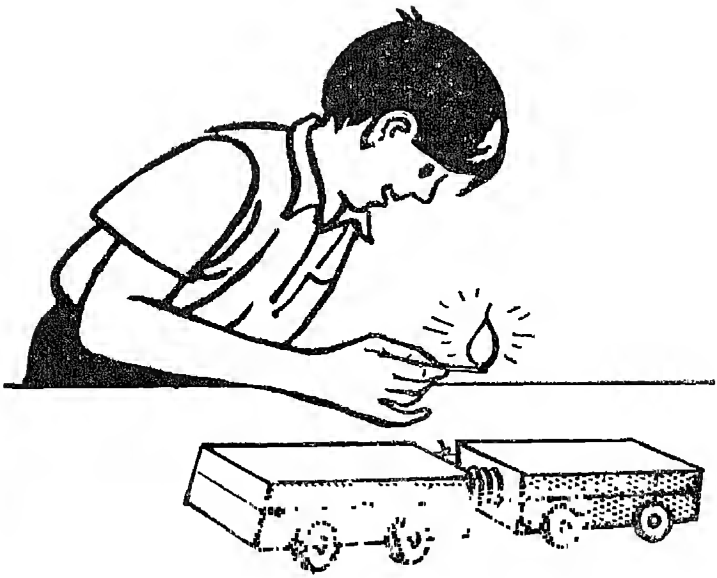


Fig 3.9

them apart? Observe the distance covered by each of them after the thread is cut. Note down your observations in the table given below. The distance covered by the two trolleys are the same, but in opposite directions. Repeat your observations with the mass of one trolley

twice, thrice and four times that of the other by adding external weights. Measure the distance in each case and note down in the table.

No. of observations	Mass of trolley		Distance of travel of trolley	
	A	B	A	B
1				
2				
3				
4				

From the above experiments you will observe that when acted by the same force a lighter trolley moves faster than a heavier trolley When the masses of the two trolleys are same they cover approximately equal distances. But when one trolley is twice as heavy as the other, the former covers a distance which is about $\frac{1}{4}$th times that of the latter. If its mass is three times then this distance is about $\frac{1}{9}$th. You can arrive at the same result by using the equation $v^2 = 2as$. Consider the result when one trolley is twice as heavy as the other. Let v_1 and v_2 be their velocities where $v_1 = 2v_2$. Since $v_1^2 = 4v_2^2$, $s_2 = \frac{1}{4} s_1$. Thus in this case the distance covered by the heavier trolley is $\frac{1}{4}$th that done by the lighter trolley. Similarly you can prove that this distance becomes $\frac{1}{9}$th, when the mass is trebled. Thus you find that for the same force acting on both the trolleys, the distance through which a trolley moves depends inversely on the

square of its mass. From the value of s thus measured, you can have an idea of velocity when $v = \sqrt{2as}$ or $v \propto \sqrt{s}$. Write down the values of mass and the distance in the following table.

No of observations	Mass of trolley		Distance of travel for trolley		Product of $m\sqrt{s}$ or mv for trolley	
	A	B	A	B	A	B
1						
2						
3						
4						
5						
6						
7						
8						

From the above observations, you find that the momentum of trolley A is equal to that of trolley B. Since the trolleys are initially at rest, their initial momentum is zero. When the two trolleys move in opposite directions under the action of the forces, their velocities as well as momentum have opposite signs. This is because momentum is a vector quantity. Since the final momenta of the trolleys are equal in magnitude and opposite in sign their total momentum is also zero. This is known as the *law of conservation of momentum* which states that *when two or more bodies collide with each other, the sum of individual momentum of all the bodies before and after the collision remains the same.*

Activity

(1) Take two trolleys and mark them as No. 1 and No. 2. Fix disc magnets provided in the kit one at end of each trolley with the north

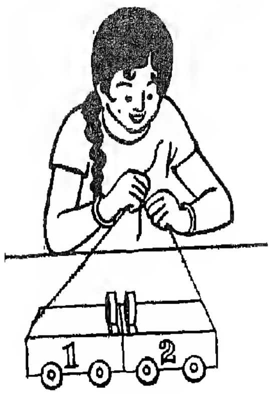


Fig 3.10

pole facing another north pole as shown in figure 3.10. Bring the trolleys near. What do you find? You will find that the trolleys are pushed apart. Again bring the trolleys near but this time keep them in that position by tying them together with a thread. Cut this thread. The trolleys move apart. Measure the distances the trolleys move. Next, place some weight on one trolley, say, No. 1 and repeat the experiment. What do you observe? Place some more weights on the same trolley and see what happens.

(2) Take two trolleys A and B of nearly equal mass. Fix a cork to trolley A and a nail to trolley B as shown in figure 3.11.

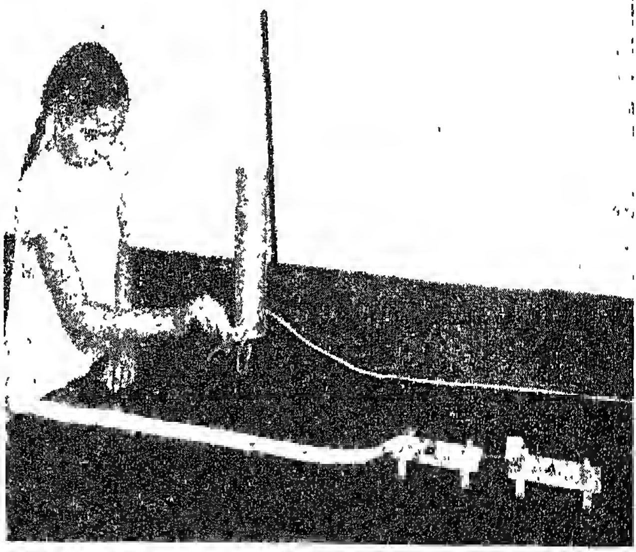


Fig 3.11

Attach one end of a paper tape to trolley B as shown in the figure. Take trolley B to one end of the table. Give it a push. It begins to move. Keep trolley A on the path of trolley B. As B collides with A, nail of trolley B fixes into the cork on trolley A. As a result, both the trolleys begin to move after collision. Separate the two trolleys. Now repeat the experiment with the water-timer on. Observe the distance between the drops before the collision between the two trolleys and after the collision. Do you find any sudden change in the distance between the drops after the collision? Are the drops after collision more separated or are they closer than they were before collision? Can you explain your observations?

Questions

(1) *When a marble is rolled on the floor it comes to rest after travelling a certain distance. As the marble moves its velocity decreases. Thus you see that during the motion of the marble, the momentum decreases. If conservation of momentum is true, what happens to the momentum of the marble?*

(2) *When firing a rifle, it is essential to keep the butt pressed hard against the shoulder to avoid injury. Why?*

(3) *A jet aircraft is said to move only when fuel exhaust moves backwards at high speed. Is this statement correct?*

(4) *A rocket moves only when fuel has been exploded and forced backwards at high speed. Is this true?*

(5) *Suppose a particle by some means suddenly breaks into two equal parts, which start moving. Explain how will they move. Can both of them move in the same direction? Can they move perpendicular to each other?*

Exercises

(1) When a 40 g cricket ball is struck with a bat, the ball travels a horizontal distance of 100 m in 2 seconds. If the bat and the ball are in contact for 0.005 s, find the average horizontal force on the ball.

(2) A 30 g steel ball moves with a velocity of 2 m/s and hits another ball of mass 180 g on its path. The lighter ball bounces back with a velocity of 50 cm/s. Find the velocity and the direction of motion of the second ball.

(3) A car of mass 5000 kg is at rest. It gains a speed of 50 m/s after a force acts on it for 20 s. Calculate the impulse.

(4) A trolley of mass 1.5 kg travels with a speed of 2 m/s and is brought to rest in 3 s. Find the force that stopped the trolley.

(5) Two balls of masses 200 g and 50 g are approaching each other with the same velocity of 2 m/s. Assume that they stick to each other after the impact. Find the direction and velocity with which the combination moves.

4 WORK AND ENERGY

4.1 Work

Work is a familiar expression which you always use in everyday conversation In villages men and women draw water from the wells. In drawing water from the well they do certain work. You also see bullocks drawing water from the well In such cases, bullocks do the work. In cities, electric pumps are fitted to draw water from the well. In this case, electric pump does the work which in villages is done by men and women or by animals.

Questions

(1) *If an electric pump draws 10 buckets of water from a well, how much work has it done compared to the work done by a man who draws one bucket of water from the same well?*

(2) *If we have two wells in two different localities having water at different depths, will the amount of work done in drawing a bucket of water from one well be equal to that done in drawing the same bucket of water from the other well?*

(3) *Is drawing a bucket of water from a well a good unit for measuring work?*

In figure 4.1, you see a building under construction. The mason lays bricks one on the top of another with mortar in between. The labourers help the mason by lifting the bricks and handing them over to him. The labourers do work. If a labourer lifts one brick and hands it over to the mason, he has done a certain amount of work Another labourer lifts two bricks at a

Fig 4.1

time and hands them over to the mason. You say that this labourer has done twice as much work.

You have seen on the road a labourer pulling a loaded cart. In pulling it he does some work. If he pulls one cart from the store to your house, he has done certain amount of work. In pulling two equally loaded carts from the store to your house, he will have done twice as much work.

In the example of drawing water from a well you will see that there is a minimum force required to draw a bucket of water. This minimum force is the force of gravity on the bucket and water. If you take a bigger

bucket and try to pull it, you have to apply a greater force. There is some relation between the work done and the force used to do that work. If F is the force that pulls a bucket of water through a height d, then the work done W is defined by

$$W=F\ d.$$

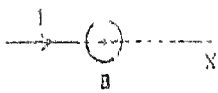


Fig 4.2 (a)

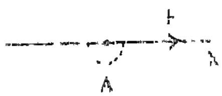


Fig. 4 2 (b)

Work is said to be done by or against a force when the point of application of the force moves in or opposite to the direction of the force It is measured by the product of the force and the displacement of the point of application along the line of action of the force. Let a force F act on a body initially at the position A as shown in figure 4.2(a). Under the action of the force F it moves to the position B along ABX. Here the force does F. AB amount of work on the body. In figure 4.2 (b) the body initially at A moves to B against the force F whose direction is along AX. The body moves along AB and does F. AB amount of work against the force F This type of force is called a retarding force.

4.2 Unit of Work

You have seen in the above expression that F is the force. There are various types of forces, but there is a common unit with reference to which all forces can be measured. This unit is one newton. Similarly the unit of distance is 1 metre. When a force of 1N acts on a body and pushes it through a distance of 1 m the work done by the force is 1 newton $\times$ 1 metre. This is taken as the unit of work and is known as one *Joule*. This name has been given in honour of a English Physicist, James P. Joule.

If the mass of a brick is 0.8 kg, then the amount of work done by the labourer in lifting a brick through a vertical height of 1m is $0.8 \times 9.8 \times 1 = 7.84$ joules. When a man draws water from a well, he also does work. Let the mass of the bucket together with the mass of water in it be equal to 6 kg. If the well is 5 m deep, the work done in lifting such a bucket against gravity is, equal to $6 \times 9.8 \times 5.0 = 294$ joules.

The work done in pulling the bucket of water through 5 m is 37.5 times the work done in lifting the brick through 1 m.

Exercises

(1) Let the mass of a bucket full of water be 5 kg. Calculate the force of gravity on this bucket full of water. If you pull this bucket of water through a height of 1 m how much work have you to do? (1 kg = 9.8 N)

(2) A labourer lifts a brick of mass 2 kg through a height of 2 m. Calculate the work done in lifting the brick.

(3) Suppose the force required to pull a cart on the road is 2000 N and the distance through which it is pulled is 1000 m, calculate the work done.

(4) Suppose the mass of a glass full of water is 500 g. Calculate the work you have to do to raise the glass through 20 cm.

(5) Calculate the work done in lifting a book of mass 500 g from the table through a height of 60 cm.

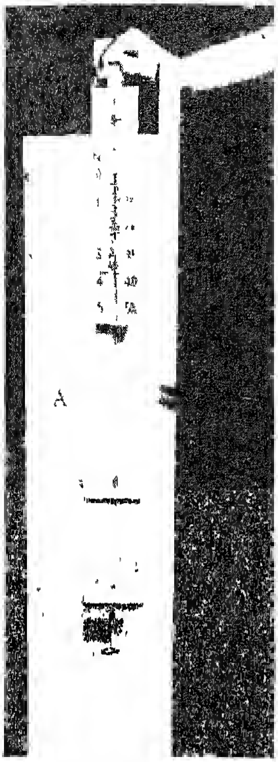


Fig 4.3

Activity

Fix a small plank A of height 1 m on the table and place it by the side of a metre scale. Let them touch each other and stand vertically as shown in figure 4.3. Now take a trolley, attach a spring balance to it and lift it slowly vertically along A through a height of 20 cm. Record your observations in the table given below. Repeat the experiment with heights say 30 cm, 40 cm, 60 cm etc. and record your observations. Calculate the work done in each case.

Dis[illegible]	[illegible] newton	W[illegible] distance) in Joule

Who does the work here?

4.3 Work done by Various Forces

You have seen that work is done by or against a force or a system of forces. There are different types of forces, all of them can do work.

Activity

(1) Place a trolley on a table and attach a spring balance to it as shown in figure 4.4.

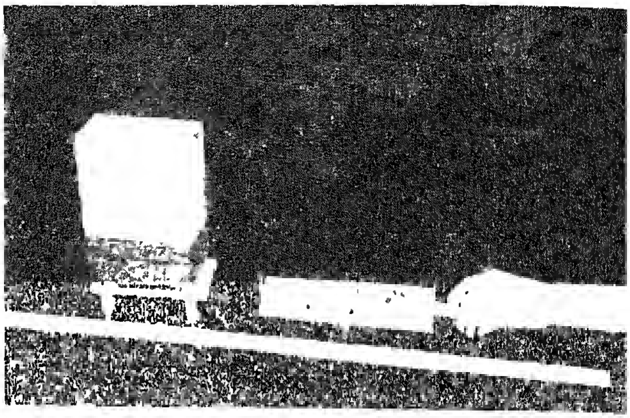


Fig 4.4

Pull the trolley through a certain distance which is measured with a scale. Name the force by or against which the work is done. What is the direction of that force? Now, place a few wooden blocks over the trolley. Is a greater force needed now to pull the trolley through the same distance? Are you doing work against the weight of the trolley or against the force of friction?

(2) Fix one end of a spring on a vertical support and the other end to a trolley placed on the table (figure 4.5). Fix one end of a string to the trolley and the other end passing over a pulley is attached to a load placed on the ground. Now compress the spring with the help of the trolley against the vertical support and let the trolley go. Do you find that the

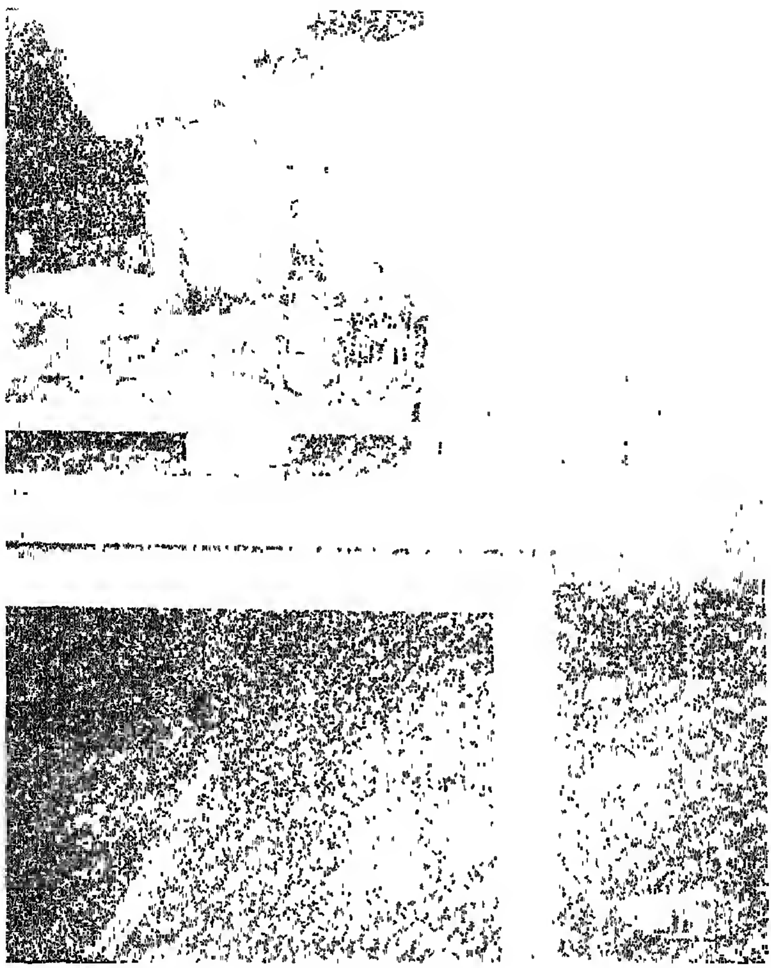


Fig. 4.5

load has been lifted through a certain distance? Who has done the work to lift the load? The compressed spring, while releasing itself, has pushed the trolley forward. Thus the work done in lifting the load through a certain distance has been done by the compressed spring.

(3) Take two trolleys A and B and fix two disc magnets at one end of each trolley. Let

the opposite poles N and S of the magnets face each other as shown in figure 4.6. Let a

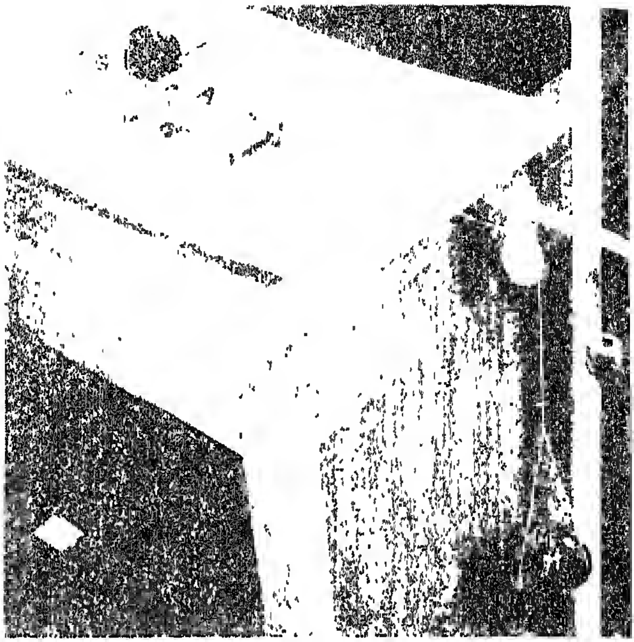


Fig 4.6

mass M be attached to one end of a string whose other end passes over a pulley and is joined to the trolley A. Bring the trolley B with S pole fixed on it gradually towards A. The N-pole fixed on the trolley A is attracted by the S-pole. As a result, the load M is lifted through a certain distance as measured by the scale. Here the magnetic force of attraction between the two opposite poles has done the work of lifting the load through a certain distance. Arrange the experiment in such a way that the magnetic force of repulsion may also do the work of lifting the load.

; 4.7

(4) The force exerted by an electric charge may also be used to do work. Suspend a balloon B from a vertical support (figure 4.7). Attach a thread to the balloon. The other end of the thread, passes over a pulley and is attached to a light mass M. This can be a small piece of foam or a piece of paper. Take an ebonite rod R and rub it briskly with a woollen cloth. Bring it near the balloon. Is the balloon pulled towards the rod? Is the load M lifted through a certain distance? Who has done the work of lifting the load? It is the electric force on the charged rod that has pulled the balloon towards it. As a result the load M attached to the balloon has been lifted.

Exercises

(1) On the surface of the earth you have to exert a force of about 9.8 N to lift a mass of 1 kg. What work you have to do in going from the ground floor to the second floor of a house which is at a height of 8 m, if your mass is 30 kg? Do you do more work if you run up the stairs?

(2) You are dragging a box of 5 kg on a floor 3.5 m long. If the force of friction is 3.0 N, how much work is done? Is any work done against the force of gravity?

(3) A book of mass 1 kg falls from a table of height 1.2 m. How much work is done? Who does the work? If you lift the book and place it on the table, how much work is done?

(4) A magnet lifts a piece of iron of mass 50 g through a vertical height of 5 cm. What is the magnetic force and how much work is done by the magnet?

(5) A trunk weighs 5 kg. How much work is done in carrying it up a flight of stairs 6 m high?

(6) A force of 500 N is used to push a cart 50 m along a horizontal walk. How much work is done?

(7) A man lifts a 2.5 kg package and places it on a shelf 2.2 m high. How much work is done?

(8) A force of 49 N is required to push a heavy almirah 15.0 m on the floor. What is the work done?

(9) Two bricks weighing 4 kg are lifted by a labourer through a height of 1.5 m. What is the amount of work done?

(10) A hammer weighs 500 g. If it is to be lifted to a height of 2 m, what is the work done?

(11) An electric pump lifts 500 kg of water through 9 m in a second. What is the amount of work done per second?

(12) A metre stick of mass 0.20 kg is lying on a table near two blocks 10 cm high (figure 4.8).

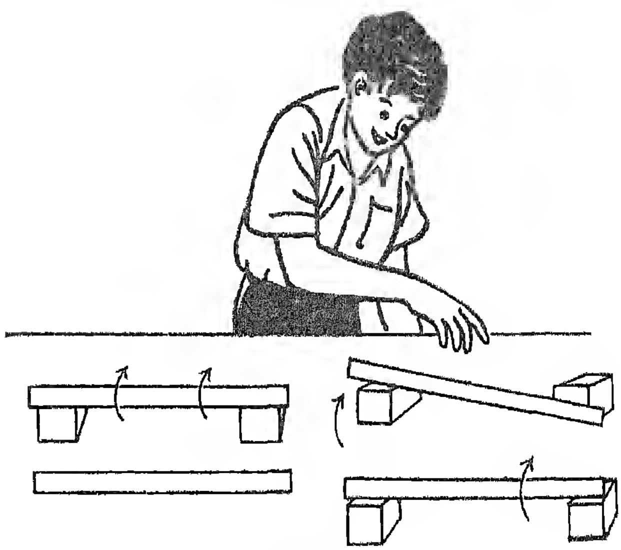


Fig 4.8

(a) If you lift the stick, holding it horizontal and put it on the blocks, how much work have you done?

(b) If you lift one end and set it on one block, and then lift the other end, setting it on the other block, how much work have you done in moving the stick?

4.4 Moving Bodies do Work

Activity

(1) Take a trolley and place it on a table. Attach a thread to this trolley and pass the other end of this thread which carries a pan, over a pulley as shown in figure 4.9. Put some weights on the pan and see that the pan just touches the ground. Pull the trolley away from the pulley. As the trolley is pulled, the weight on

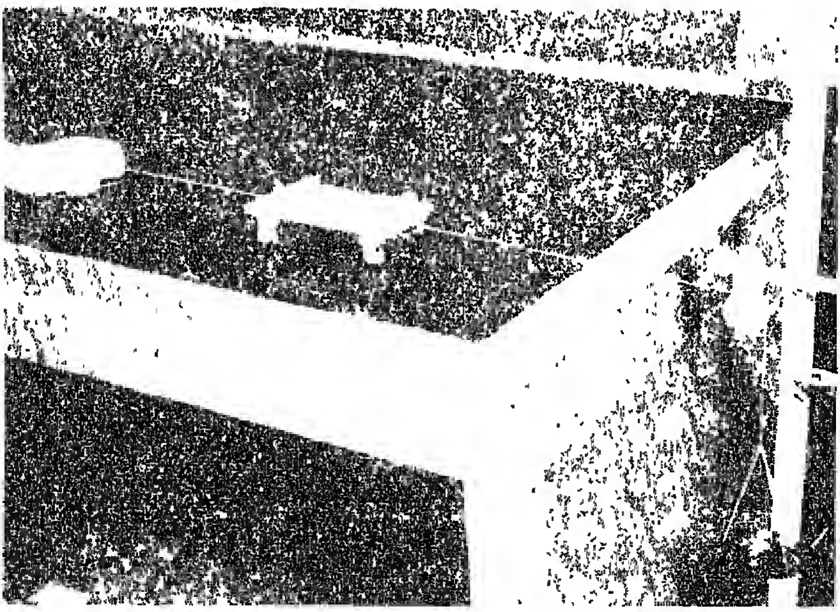


Fig 4.9

the pan is raised through a certain height. You can read this height by placing a scale along the thread as shown in the figure. You find that the moving trolley does work when it lifts a load through a certain height against the force of gravity.

(2) Construct an inclined plane with a thin board and the wooden blocks or books as in figure 4.10.

Fig 4.10

Place a wooden block at the end of the ramp. Take a marble up the inclined plane. Let it go It hits the block. What happens to the block? Is the block displaced through a certain distance? If so, does it mean that the marble

moving down the inclined plane does work? Repeat the experiment by releasing marble through different heights on the inclined plane. What do you observe? What conclusions will you draw from this experiment?

(3) Take a circular wooden disc. Fix four blades on opposite sides of this disc as shown in figure 4.11. Pass a nail through the centre of

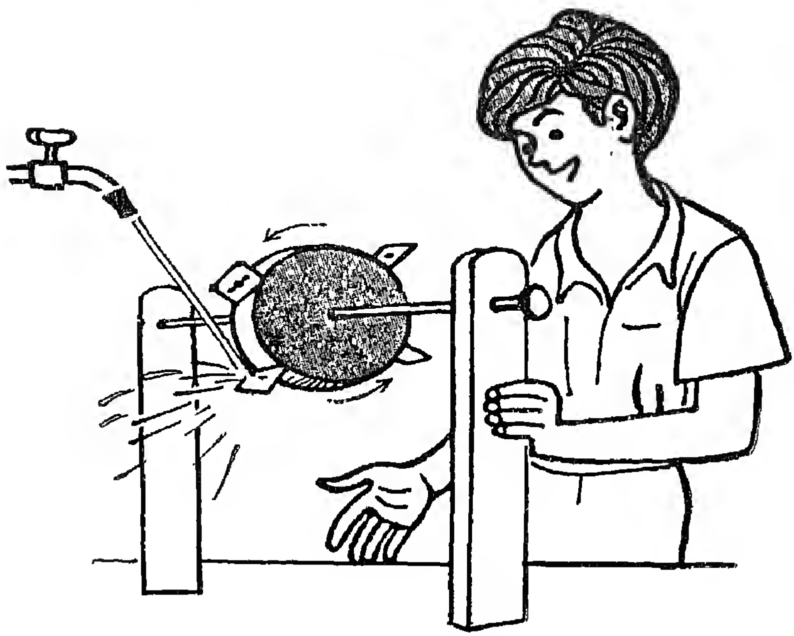


Fig 4 11

the disc. Support the nail on two wooden grooves such that the disc can rotate when given a push. Take a rubber tube and attach one end to a water tap. Compress the other end of the tube by the thumb so that a water jet is formed. Strike the blades with the water jet. What do you find? You will find that the disc rotates. Tie one end of a thread to the nail on

one side and suspend a small weight at the other end. As the disc rotates, the weight is raised to a certain height The moving jet of water, therefore, does work. Repeat the experiment by shooting the blades with water jet from the top as well as from the sides What do you find?

Fig 4.12

Not only the moving water but also the moving air can do work. This is seen in a windmill which moves when air strikes its blades. The photograph of a windmill located at the Jadavpur University, Calcutta is shown in figure 4.12.

(4) Take the paper toy (provided in the kit and shown in figure 4.13). It consists of curved paper strips fixed on a circular metal piece A circular metal wire passes through the centre of the metal strip, such that the disc can rotate about this wire The wire is bent at the other end and is fixed to a thin wooden rod. Hold the wooden rod and move your hands. You will find that the air strikes the paper strips and the disc rotates. Now run and see what happens Does this show that moving air can do work?

Fig 4.13

4.5 Energy

From the above examples you see that a moving body can do work. The capacity of a body to do work is called its energy. The energy of a moving body is called its *kinetic energy* and arises due to motion of the body. A moving motor car, an athlete running on

a track, a bullet fired from a gun, strong wind, running water, a bullock drawing water from a well, all possess kinetic energy.

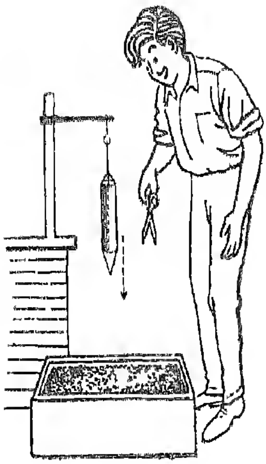


Fig. 4.14

4.6 Factor which determine the Kinetic Energy (Dependence on Mass and Velocity)

Take a small hollow pointed metal cylinder of mass m (provided in the kit) and keep it on a stand at a certain height from the table (figure 4.14). Now, take a cardboard box and fill it with sand. Place this box on the floor exactly below the pointed cylinder. Release the cylinder from the stand such that it hits the sand. Note the depth upto which the metal cylinder goes into the sand. Suppose h is the height through which the cylinder falls and v the velocity with which the cylinder strikes the sand, then from the equation you read earlier:

$$v^2 = u^2 + 2\,gh.$$

Since initial velocity $u = 0$,

$$v^2 = 2gh.$$

Since g is a constant at a particular place, the velocity acquired will depend on the height through which it falls. Now when the cylinder strikes the sand, it goes a certain depth and comes to a stop. Why does it come to a stop? It is because the sand particles offers a frictional resistance to it. This frictional force retards the motion of the cylinder which ultimately comes to a stop. If s is the depth upto which the cylinder goes into the sand and F the frictional force due to the sand particles against which the cylinder moves a distance s, then the work done will be F.s. This then is the measure of the kinetic energy of the cylinder.

Now fill the cylinder with sand and release it again. You will find that it has penetrated more in the sand. Next, fill the cylinder with lead shots and note the depth of penetration.

From the above experiments, you will find that as the mass of the cylinder increases, penetration into the sand also increases. This shows that the kinetic energy of a body moving at a particular speed increases as its mass increases.

Now empty the cylinder and drop it from different heights. Compare the depths of penetration for each fall. You will find that greater penetration is produced when the object is dropped from a greater height. This means that as the height increases, the speed increases. When the mass is same, the object acquires greater kinetic energy the faster it is moving. The kinetic energy of an object depends on the mass and its speed.

4.7 Measurement of kinetic Energy of a Body

Fig 4.15

Suppose a marble of mass m is given a push (figure 4.15). It is set into motion and acquires a velocity v. After moving a certain distance it loses its velocity v and ultimately comes to a stop. Why does it come to a stop? The marble is moving against the force of friction F. This force retards the motion of the marble. The velocity of the marble decreases and ultimately becomes zero. Therefore, from the equations you read earlier

$0 = v^2 - 2as.$ (The negative sign indicates that the marble moves against the force of friction)

$\therefore\ 2a\ s = v^2,$

or $\quad as = \frac{v^2}{2}$.

Multiplying both sides by m

$$mas = \frac{1}{2} mv^2 \qquad (1)$$

Now, since the marble has moved a distance s against the force of friction F, the work W done by the marble is given by

$$\text{Force} \times \text{distance} = F.\,s. \qquad (2)$$

The frictional force F as you have seen earlier retards the motion of the marble and that it produces a retardation a.

$$\therefore F = ma. \qquad (3)$$

Again from equation (1)

$$mas = \frac{1}{2} mv^2$$

But ma = F (from equation 3)

$$\therefore F.\,s = \frac{1}{2} mv^2.$$

But $F.\,s = W$ (from equation 2).

Therefore, you have $W = \frac{1}{2} mv^2$.

This shows that $\frac{1}{2} mv^2$ is the work done by a marble of mass m moving with a velocity v, before coming to rest. This then is the *kinetic energy* or the energy due to motion of the marble.

Thus knowing the mass and velocity, you can find the kinetic energy of a body.

4.8 Change in kinetic energy

Suppose now the marble has its velocity changed from v to u under the action of force F as shown in the same figure 4.15.

Then the kinetic energy at A is $\frac{1}{2}mv^2$ and the kinetic energy at B is $\frac{1}{2}mu^2$.

The change in kinetic energy$=(\frac{1}{2}mv^2-\frac{1}{2}mu^2)$.

$$\text{But } v^2=u^2+2as.$$
$$\therefore 2as=v^2-u^2.$$
$$\begin{aligned}\therefore \text{The change in kinetic energy} &= \tfrac{1}{2}\, m\,(v^2-u^2)\\ &= \tfrac{1}{2}\, m\; 2as\\ &= mas\\ &= F.s.\end{aligned}$$

This change in the kinetic energy is equal to the work done by the force$=F.s$.

$$\begin{aligned}\therefore \text{Work done}\quad W &= F.s\\ &= \text{Change in kinetic energy.}\end{aligned}$$

If the work is done by the force, kinetic energy increases. If on the other hand, work is done against the force, kinetic energy decreases.

4.9 Potential or stored energy

You have seen above that moving bodies are capable of doing work. Is there any other state in which a body can do work? There are bodies capable of doing work even when they are not in motion.

You have seen that in a game of marbles, you bend your finger to throw a marble at a distance. When you bend the finger, you do some work on the finger. The finger, however, tries to come back to its original position. When you release the finger, it comes to its original position and in this process throws the marble at a distance. If you bend the finger a little more, the marble is thrown to a still greater distance. The work that you did on the finger is stored in it, till you release the finger. The moment you release the finger you start utilising this stored energy in throwing the marble to a distance. The bent finger, therefore, has the capacity to do work.

A bent pole has also the capacity to do work. Thus in a pole vault, a bent pole can lift an athlete to a greater height and throw him to a considerable distance.

Activity

(1) Take a hacksaw blade. Fix it in a stand as shown in figure 4.16. Bend the hacksaw by a

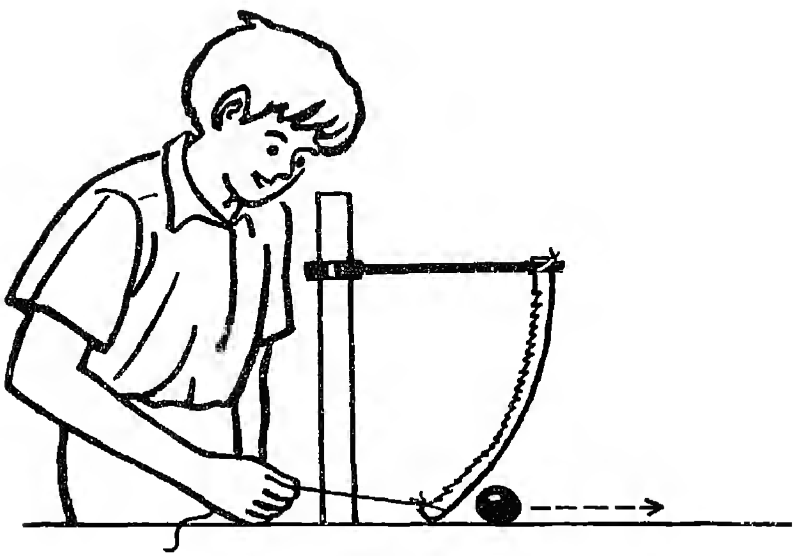


Fig. 4.16

little amount and keep a marble near the bent part. Release your hand. What do you find? Does the hacksaw blade possess capacity to do work when bent from the normal position?

(2) Take a coiled spring and fix it to a support as shown in figure 4.17. Compress the spring

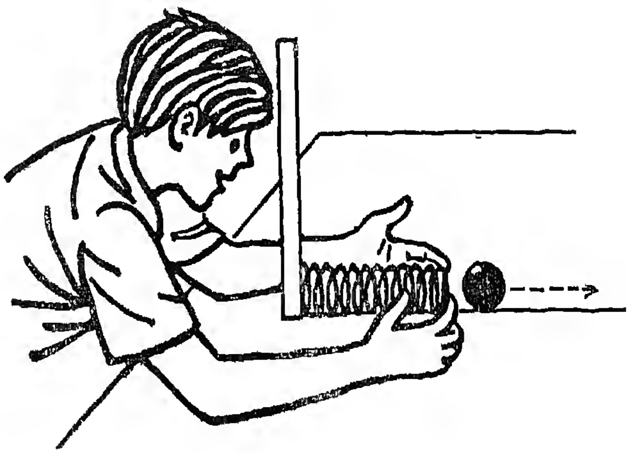


Fig 4.17

by applying a force at the free end of the spring. Now place a marble near the compressed end. Release your hand. The marble is pushed forward. When you compress the spring, the work is done on the spring against the force of tension in the spring. Now when you release the spring, the work that was stored in it is used in pushing the marble to a certain distance. This shows that the spring in the compressed position has the ability to do work.

(3) Take a spring, hold it vertically and compress it by a piece of plank as shown in figure

4.18 Keep the spring in this compressed position by means of threads. Note the position

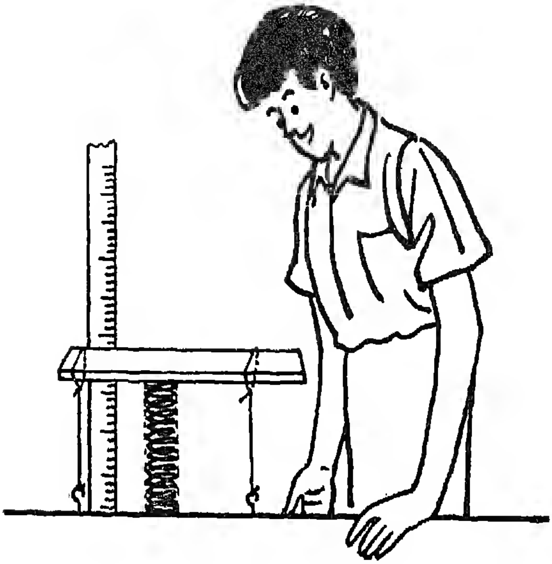


Fig 4.18

of the plank on the compressed spring. This you can do by placing a scale behind the compressed spring. Now cut both the threads. What happens to the load? What does this suggest?

(4) Take a spring, compress it and hold the compressed ends together by means of a thread as shown in figure 4.19. Place two marbles at the two ends of the spring. Cut the thread. What happens to the marbles? What inference do you draw from this experiment?

Fig. 4.19

(5) Take two trolleys and connect them together by means of a rubber band as shown in

figure 4.20. Stretch the two trolleys apart and then release them. You will find that the

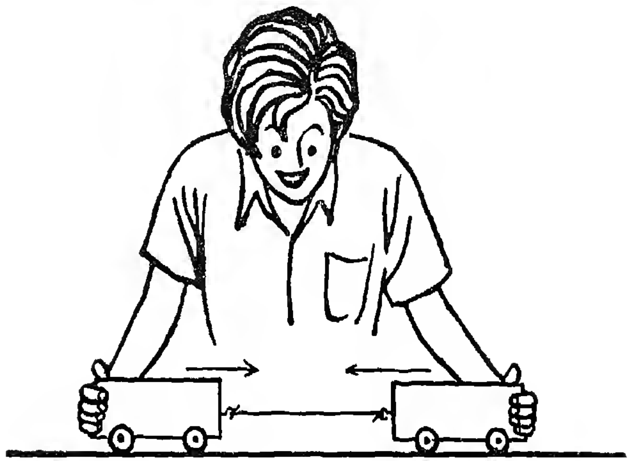


Fig. 4.20

trolleys move towards each other. When you stretch the rubber band, you do some work on the rubber band When you release the trolleys, the work that was stored in the rubber band is utilized in moving the trolleys. The rubber band in the stretched position has thus the ability to do work.

Again, a brick placed at the top of a table has the capacity to do work. This is so because, when the brick is allowed to fall on sand kept on the floor, it moves a certain distance in the sand before it comes to a stop. This shows that the bodies when released from height have the capacity to do work. Similarly water stored in a dam has the capacity to do work. Water falling from a higher level does work in running turbines and which in turn are used to generate electricity.

From the above examples, you find that a compressed spring, a stretched rubber band and a bent strip can do work in setting a body in motion. Also a load falling from a height can do work. In all these cases, the capacity or the ability to do work is due either to the changed condition of the body or to its position. A compressed spring, a stretched rubber band, a bent strip, etc., do work on account of their changed state. In all cases of bending, stretching, or twisting, the material is said to be distorted or strained. On the other hand in the case of a brick, the ability of the body to do work is due to its raised position. The capacity or the ability to do work due to the position or the strained state of a body is called the *potential energy* or the *stored energy*.

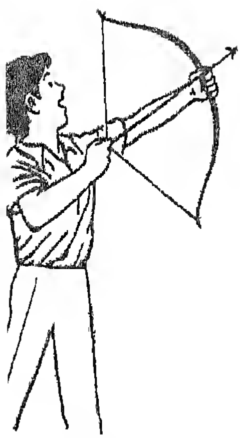


Fig. 4.21

Consider some more examples of potential energy.

When you bend a bow by pulling the string, you are doing some work in bending the bow (figure 4.21). This means that you are giving some energy to the bow and this energy in the bent position of the bow, is potential energy. When you release the string, the potential energy that was stored in the bow goes off in the form of kinetic energy of the arrow.

A compressed gas in a cylinder has also got potential energy. Because of this when the gas is allowed to expand, it can do work. In a steam engine when the compressed steam expands, it forces the wheels of the engine to move.

When you wind a watch, the spring in it is tightened. It then possesses potential energy. This potential energy is slowly spent in keeping the watch running till

after sometime this energy is completely transformed and you have to restore this energy again by rewinding the watch to keep it running.

The storing of energy as potential energy can also be explained by simple electrical experiments.

Fig 4.22

Suppose there are two charges +Q at a point A and +q at the point B (figure 4.22). If you move the charge +q towards A you have to do work against the force of repulsion. This work you do is stored as the electrical potential energy of the charge +q.

4.10 Dependence of Potential Energy on Mass and Height

Take a hollow pointed metal cylinder as before and keep it on a stand. Keep a cardboard box containing sand on the floor just below the pointed cylinder (figure 4.14). With the help of a spring balance find the mass of the cylinder. Release the cylinder. It falls on the cardboard box containing sand and penetrates through certain distance. Next fill the cylinder with lead shots, sand, chalk pieces, etc. Measure the mass in each case. Release the cylinder by turn from the same height. Note the depth of penetration in the sand in each case. You will find that the larger mass will penetrate more in the sand. The greater the mass, the greater is the potential energy. Thus potential energy depends on mass.

Next, empty the cylinder and drop it from various heights. Note the penetration in each case. You will find that greater penetration is obtained when the cylinder is released from greater height. Thus the potential energy acquired by the cylinder depends also on the height through which the cylinder falls.

4.11 Measurement of Potential Energy

If m is the mass of the cylinder lifted through a height h, then the work done against gravity is mgh. You know, W=F. d.; but here F=mg, because the body is pulled by the earth towards its centre with a force mg and d=h.

This work done on the cylinder is stored as potential energy at the height h, so that the potential energy is mgh. You now determine the potential energy in the case of a compressed spring, catapult, bow, etc.

Consider again the case of a spring which is compressed. When you compress the spring, work is done on the spring against the force of tension in the spring. Therefore, the potential energy of a spring which is compressed is equal to the work done against the force of tension.

In the same way, when you stretch a catapult or bend a bow by pulling the string, the potential energy is equal to the work done against elastic forces of the bow.

4.12 Conversion of Kinetic Energy into Potential Energy.

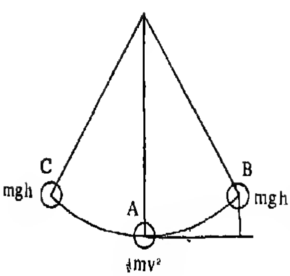


Fig 4.23

Take a simple pendulum as shown in figure 4.23. A is the rest position. Let it swing from A to B, B to A, A to C and back to A. When the bob of the pendulum is at B, it is momentarily at rest, so that its kinetic energy is zero (v=0). But when it is slightly raised through a height h from its position at A, all the energy at B is the potential energy, mgh. When the bob moves from B, all its potential energy is converted into kinetic energy and it is maximum at A and is $\frac{1}{2}$ mv^2. Due to inertia the bob

passes through the position A and goes upto C where it changes its direction of motion. At C, the energy is potential energy because v is 0. At any other intermediate position, the energy will be partly kinetic and partly potential. Now find the velocity at A.

$$\text{At A,} \quad \tfrac{1}{2}\,mv^2 = mgh.$$
$$\therefore \qquad v^2 = 2\,gh.$$

Consider another example. Take a trolley and a spring fixed to a support as shown in figure 4.24. Push the trolley and let it strike the fixed spring with a

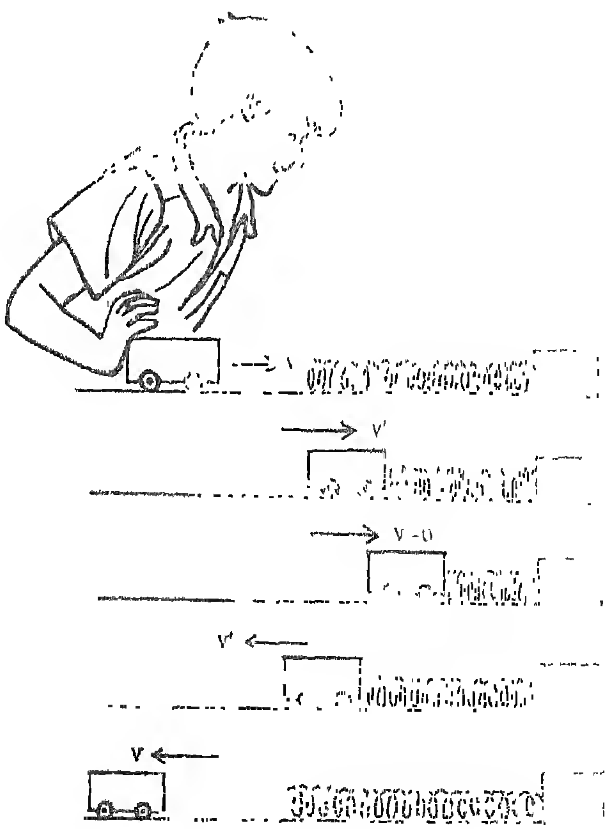


Fig 4.24

velocity v. The spring is compressed and the trolley slows down such that the velocity is reduced from v to v′. The trolley loses some kinetic energy which is gained by the spring in the form of potential energy. When the trolley is brought to rest (v=0), the spring has been compressed to its maximum so that the kinetic energy of the trolley is wholly transferred to the compressed spring as its potential energy. Now the compressed spring exerts a force on the trolley which is set into motion in the opposite direction. So, the potential energy of the spring is gradually transferred to the trolley as its kinetic energy. When the spring is completely released from its state of compression, its potential energy is wholly transferred to the trolley as the kinetic energy and the trolley attains its initial velocity v.

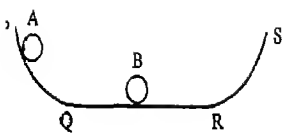


Fig. 4.25

Questions

Take a channel PQRS as shown in figure 4.25.

(*a*) *What happens to the speed of a marble A as it comes down the slope?*

(*b*) *If you lift the marble A upto a larger height, is the work done by you larger, smaller or same?*

(*c*) *What happens when the marble A strikes a marble B kept at the bottom of the slope?*

(*d*) *When the marble B reaches some height on slope RS, is some work done on it? Who does this work?*

4.13 Trolley Experiment to show that the Sum of Kinetic and Potential Energy is a Constant

Take a smooth glass plate so that friction is reduced and place a trolley on it. Tie a thread and a paper tape

to the same end of the trolley and pass the other end of the thread over a pulley which carries a pan (figure 4.26).

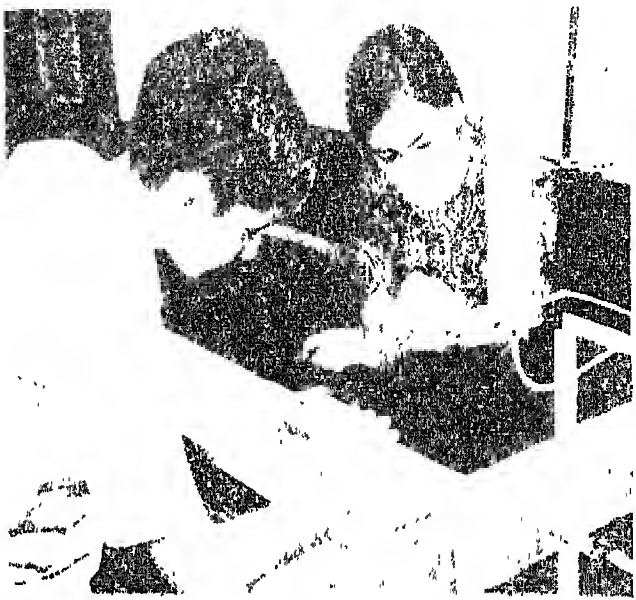


Fig 4.26

Place a scale behind the thread such that the movement of the pan can be read on the scale. Take a water-timer and adjust it so that the water drops fall on the paper tape. Note the time between two successive drops. This you can do by noting the time for 101 drops and then dividing the total time by 100. Now bring the trolley at the edge of the table. Put some weight on the pan when the thread is slackened. Start your water-timer and give a push to the trolley. The trolley moves forward with a certain velocity v_1 until the string becomes taut. The trolley then starts lifting the pan through a certain height and its velocity in the same direction reduces to v_2. As the trolley moves forward, water drops are recorded on the paper tape. Find the distance between con-

secutive drops and calculate the velocity v_1 and v_2. Measure the distance through which the pan is raised. Also find the mass on the pan. Knowing the mass of the trolley and its velocity v_1 and v_2 you can calculate its loss of kinetic energy required to raise the weight through a height h. Similarly you can calculate the potential energy of the weight by substituting the values of h, g and m in the relation mgh. From the calculations you will find that the kinetic energy lost by the trolley is equal to the potential energy gained by the mass raised through a certain height.

4.14 Energy Transformation

The kinetic energy and potential energy together is known as *mechanical energy*. In addition to this there are a few other forms of energy such as *sound*, *heat*, *light*, *electricity*, *energy of the nucleus* and the *chemical energy*. The study of all forms of energy and their transformation is one of major tasks of physics. Mass can now be transformed into energy. This is given by the relation $E=mc^2$ where c is the velocity of light. The total quantity of energy in the universe is constant although energy changes from one form into another. Consider some of these forms.

(i) *Sound energy*

When a gun is fired the chemical energy within the gun powder is released and much of it goes into the kinetic energy of the bullet. Some, however, goes into the sound energy of the explosion.

(ii) *Electrical energy*

You know that water in a dam has potential energy. When it is released to flow downwards, it has kinetic

energy which can be used to turn turbo-generators for the production of electricity.

(iii) *Heat energy*

Thermal energy is due to the kinetic energy of the atoms or molecules of a substance. If you connect a torch bulb across the battery, what happens? You will find that the bulb has become a bit warm. Thus electrical energy is converted into heat energy.

(iv) *Light energy*

In an electric bulb, due to the passage of electric current through the wire the temperature of the filament is raised so much that it glows white and gives out light energy.

(v) *Nuclear energy*

Nuclear energy is now being very widely used in generating power. Here the heat from nuclear reaction produces steam, and the steam turbine operates the generators.

(vi) *Chemical energy*

In a battery the energy due to chemical reaction is transformed into electrical energy.

You know that a substance can exist in three different states—solid, liquid and gaseous. What happens when a substance changes from one state into another? Why is heat necessary to bring about the change? How does heat affect the structure of matter?

5.1 Molecular motion in gases

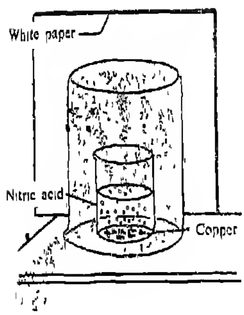


Fig. 5.1

Take a small beaker and place into it a few pieces of copper. Pour a little concentrated nitric acid on the copper and immediately cover the beaker and its contents with a larger beaker. Look at figure 5.1 to see how to do this. The copper and nitric acid react forming brown fumes of a gas called nitrogen dioxide. After a short time the brown gas fills the first beaker, overflows it, and then fills the second beaker. But it does not stop there. It spreads in the room gradually and is found to have travelled quite a long way from the original site. This spreading of gases is called *diffusion*. Do you observe that the gas spreads in all directions—upwards, downwards and sideways? It appears to spread in every direction. From the above it is clear that the gas particles move in all possible directions.

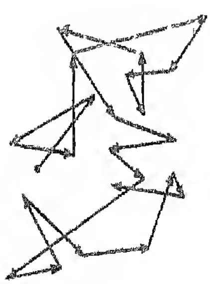


Fig. 5.2

Billions and billions of gas molecules are contained in a small space (about 3×10^{19} molecules per cm^3). Obviously they will collide with one another and with the walls of the container. The number of collisions of molecules will be many billions per second. At every collision every molecule bounces off and its direction of motion changes. The pattern will be a zig-zag one as shown in figure 5.2. The zig-zag motion of the molecules is similar to your motion when you try to make your way through a crowd. You may be moving very fast,

but your average displacement will probably be very small depending upon the number of encounters you make with the persons in the crowd. Almost a similar situation arises in the case of gas molecules. Although they travel at a high speed of about 5×10^2m/s, the average distance travelled between two successive collisions is very small (about 10^{-5} cm). This average distance between two successive collisions is called the *mean free path.* Hence the rate at which the gas spreads is much small though the speed of the gas molecules are quite large.

Activity

Fig 5 3

(1) Take a glass tube with cotton plugs at both ends (figure 5.3). Soak one plug with ammonia solution and the other plug with dilute hydrogen chloride solution. Observe how a disc of white fog appears where the two gases meet in the tube

(2) Close the doors and windows of a class room to prevent air currents. Open the mouth of a fairly strong and good scent bottle placed at the centre of the room. Everyone in the class sits with his eyes closed. The teacher asks the students to raise hands and speak out their names when they smell the scent. Do you expect that all will smell the scent at the same time? Observe how students sitting nearer to the bottle smell the scent first and those sitting farthest smell it the last. Finally every one in the room will get the smell. You can measure the distance of your seat from the bottle of the scent and note the time when you

smell the scent. Thus you can get an idea about the motion of the molecules of the scent in air.

(3) Allow a beam of light to pass through a creak or hole in the window of a room. Do you see floating dust particles moving at random even when there is no air currents in the room? Why do the dust particles dance in that way? You will find as if they are being pushed in all possible directions. It is the rapidly moving gas molecules in the room that push them from all directions and make them dance in that way.

You have seen earlier that the forces between molecules are almost negligible in gases. Here you find how the gas molecules are free to move. This molecular motion is not confined to gases only. The molecules of liquids and solids have motion also.

5.2 Molecular motion in liquids—Brownian motion

Some two hundred years back, it was Daniell Bernouilli who imagined gases as consisting of swarms of rapidly moving particles. At the beginning of the nineteenth century, the concepts of atoms and molecules were given by Dalton and Avogadro. In 1827, an English botanist, Robert Brown, was using a microscope to look at some tiny pollen grains floating in water. To his surprise he found that, the grains kept dancing around with a peculiar trembling movement. The puzzling thing about this darting and dancing movement was that it never stopped. Brown was unable to account for what he discovered. It was not until

many years later that Perrin and others found an explanation of this motion, now known as *Brownian motion*. The molecules of liquids, like those of gases are also in swift motion. When the tiny pollen grains are hit from all sides by rapidly moving water molecules, the grains are pushed around. This haphazard (random) motion is Brownian motion.

5.3 Experiment to show Brownian motion

Take some tap water in a beaker (figure 5.4) Boil and filter it to remove suspended impurities. Add a small amount of aluminium powder to it and a few

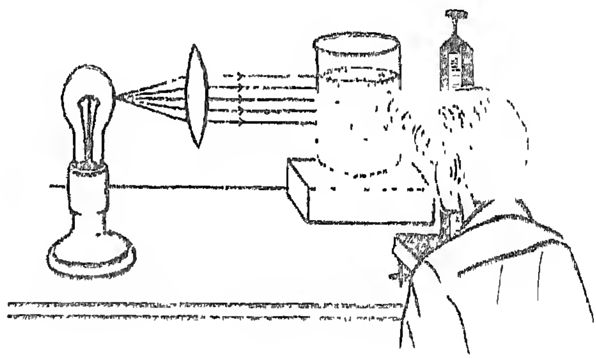


Fig 5.4

drops of detergent to prevent the aluminium particles from sticking together. Look at the solution through a microscope (any ordinary microscope such as one used by biologists will do) and watch the powder settle in water. The very large particles will quickly sink to the bottom as grains of sand would. Many of the smaller particles, however, will remain suspended in the liquid. Let the beaker stand for sometime. Now darken the room as much as possible and shine a powerful light through the liquid. You will see that the larger

particles will appear not to move about. But the smaller ones will twinkle like stars. Can you account for this observation? The bigger particles are big enough not to be pushed by the water molecules. Hence they do not move. But the tiny particles are hit by the swiftly moving water molecules. So, they move from one place to another. In doing so, they reflect light in different directions, producing twinkling.

Place this beaker in a hot water bath. After some time take the beaker out from the bath and look at it through a microscope as you did earlier. You will find that the molecular movement has increased considerably. Do you find any relation between heat and molecular motion? The particles of matter are in a state of constant agitation. Heating increases this agitation. In other words, heat increases the motion of the molecules. As a consequence, more collisions take place in a given time.

Next place the beaker in an ice-water bath for sometime. Take the beaker out from the bath and repeat your observation. What do you find?

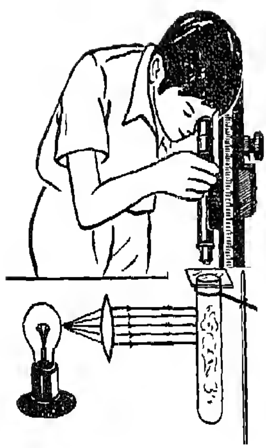


Fig 5.5

Activity

Take a small test tube preferably with the bottom blackened. Hold it in vertical position. Concentrate a horizontal narrow beam of light on the middle part of the tube preferably in a dark room. Admit some smoke into the tube from the top and cover it with a glass slide and look at the inside of the tube from the top with the help of a microscope (figure 5.5) What do you observe?

From the above experiments and observations, you come to the following conclusions:—

(I) Molecules of a substance are in constant agitation.

(II) Heat increases the agitation of the molecules and makes them move faster.

(III) When a substance is cooled, molecular agitation decreases.

5.4 Temperature

You have seen that the molecular motion can be increased by heating. As the molecules are in motion, they have a certain kinetic energy. This average energy remains the same, provided you neither heat nor cool the substance. In other words, the average energy of the moving molecules is directly connected with the state of hotness or coldness of the substance. Temperature depends upon the average kinetic energy of the molecules.

5.5 Molecular models

There are other consequences of molecular motion. Each of the molecules has a certain momentum at a given instant of time which changes with time. This is because of the collisions between the molecules and the walls of the enclosure. In order to study the effects of this molecular motion, you can build up a model of gas using a large number of beads in an enclosure. Try to compare the motion of the beads with what you actually find in the case of a gas. Take a tray of about $30 \times 20 \times 2$cm with vertical edges (figure 5.6). Put about 25 to 30 plastic beads of the same size and

Fig. 5.6

colour in the tray. Keep the tray in constant agitation by holding it in hand and shaking it continuously. Observe the motion of the beads. You will find that the beads collide amongst themselves and against the edges (walls) of the tray. Observe an individual bead. This you can do easily by colouring a bead. You will find that its motion is zig-zag and irregular. At every collision between this bead and other beads and also during the collision of this bead and the walls of the tray, the speed of the bead changes its direction as well as magnitude. You can substitute one of the beads by a bead which is about 5 times bigger than the previous one. Now, observe the motion of this bigger bead. Is there any difference between the motion of this bead and the other beads in the tray? Do you find any similarity between the motion of this bead and the Brownian motion which you had observed earlier?

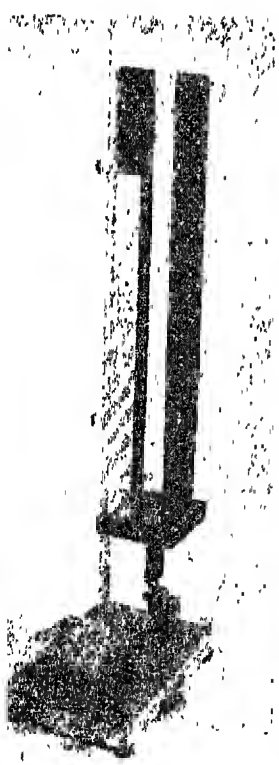


Fig. 5.7

Observe the motion of the beads in the tray a little more closely. At any given instant, do you find the motion of all the beads identical? Are all of them moving in the same direction? Do all of them strike the walls of the tray at the same time? Is there any bead which does not strike the walls of the tray at all?

Improve your model by allowing the beads to move not only in one plane, as in the tray, but in all directions. The model is shown in figure 5.7. It consists of an agitator, whose vibrations can be controlled. A number of beads are put on the top of the agitator and enclosed in the glass tube. As the agitator vibrates, the beads move up and down. Do you find, as in the previous case, that the motion of the beads are random? Secondly, observe that all the beads do not move with the same velocity at the same time. As

in the previous case, the beads collide amongst themselves and against the walls of the tube. Put in one bigger bead, and observe its motion. Does it show a kind of Brownian motion?

Increase the agitation considerably. You will find some of the beads go out of the glass tube. If you increase the agitation further, more and more beads go out. Isn't it similar to the phenomena of *evaporation* in which the molecules of the liquid escape from the surface as *vapour*? Does not evaporation increase on heating, i.e. with greater agitation of the molecules?

Fig. 5 8

In addition to the above observations, try to understand what other effects can be explained with this model. Take the model and put in about 25 to 30 beads in the tube Put a light foam-disc or card board on top of them (figure 5.8). This serves as the lid of the container. Switch on the agitator and observe what happens. You will see that the beads collide with the lid. As a consequence the lid is pushed up and held at a certain position. If you increase the agitation, the lid is pushed farther and the beads can now move about in a greater space (i.e. volume). The lid has a certain weight and when it is held at a position, the collisions of the beads are large enough to support this weight. Let m be the mass of the lid. Then the force acting downwards will be its weight, mg. Since the lid is held stationary at a particular position because of the collisions of the beads, it is easy to see that this force mg acting downwards must be balanced by an equal force acting upwards due to collisions.

How can collisions give rise to a force? Take a thin metal strip fixed between two points A and B as shown in figure 5.9. Take a marble and slide it towards the

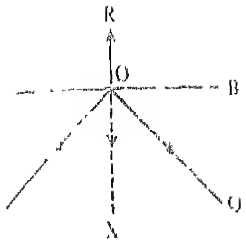


Fig. 5 9

strip as shown by PO. On colliding with the strip, the marble begins to move along OQ and you will find the strip pushed up along OR, normal to the strip. Assume the mass of the marble as m and its velocity v. You will find through a series of experiments that on extending RO to X, the angle POX is equal to angle QOX for every collision. Assuming that the marble moves along OQ with the same velocity v, you find that the momentum mv of the marble along PO has, on collision, changed to the momentum mv along OQ. You know that momentum is a vector and although its magnitude remains the same its direction has changed. So there is change in the momentum of the marble on collision with the strip. This change in momentum implies a force acting on the marble. This force acts along the direction of the change in momentum. You see, therefore, that the direction of the force on the marble is along OX (which is perpendicular to AB). This is the reaction of the strip on the marble. The action of the marble is of course an equal and opposite force on the metal strip in the direction OR. Thus you find that at every collision, there will be a force on the metal strip to push it back in a direction perpendicular to AB. This force is greater, larger the momentum of the marble.

Questions

(1) *Instead of the metal strip AB, if you take rubber strip in figure 5.9 and slide marbles at it continuously from one side will the rubber strip show a uniform bending?*

As the beads are agitated, they move with various velocities and hence have different momentum. The beads strike the lid and are reflected back. At each of the collisions, there must be a force on the lid pushing

it up. You have seen that at any instant, different beads move with different velocities. The force on the lid due to these collisions, therefore, varies from one collision to another. However, you find that the average force remains constant. This is because the collisions are too frequent. The lid does not have time enough to respond to the individual collisions. This can be shown by decreasing the number of beads, say, to 4 or 5. You now find that for a particular agitation, the disc moves up and down. As you increase the number of beads, the number of collisions increases and the lid records the impact of the average force. If the mass of the disc is m, then the average force supporting the disc is mg. This force acts over the entire area A of the disc. Hence the magnitude of the force per unit area on the disc is $\frac{mg}{A}$ N/m^2 and this quantity is called *pressure*. Although this pressure is due to the collisions, it does not represent individual collision. It is an average effect of a number of collisions.

Increase the agitation in the above experiment and see that the disc is pushed up more. The pressure due to the motion of the beads is still $\frac{mg}{A}$ N/m^2, but the space in which the beads can now move has increased. Define the space in which the beads move as the *volume* of the system. You will see that this volume has nothing to do with the volume of the beads. In addition to the two quantities, namely pressure, denoted by p and volume, denoted by V, you have a third quantity which is the agitation or the average kinetic energy of the moving beads. You know this is related to temperature T. You get three physical quantities which describe the conditions or the state of the system. They are pressure, volume and temperature.

Exercises

1. Fill in each gap in the following with a correct word:—

(i) The average magnitude of the force per unit area is called————.

(ii) For a given force, the pressure will increase if area————.

2. A boy weighs 30 kg and the area of one of his feet is 0.02 m^2. Find the pressure exerted by him when he walks and also when he stands. Calculate the pressure exerted by him when he lies down on his back (area 0.75 m^2). Which pressure is greater?

3. Explain why

(i) Your feet sink in sand when you stand on them more than your body when you lie down on the same heap of sand.

(ii) Your feet are pricked more by stone and bricks with sharp points than by smooth pavement.

(iii) You can cut a thing more easily with a knife having a sharp edge than you can do with a knife whose edge is blunt.

(iv) Nails and pins can be easily pressed into soft articles like paper, leather, wood, etc.

(v) You cannot easily break a nut by pressing it with your hands, but you can do so with the help of a nut-cracker having tooth-like edges, (fig. 5.10). What would happen if the edges are smooth and flat?

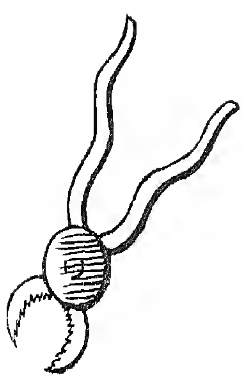


Fig 5 10

4. A book of mass 0.5 kg. is lying on its flat surface of area $0.40 \times 0.27 m^2$. What is the pressure exerted by the book? If the same book is made to stand on its longer edge-surface of area $0.40 \times 0.04 m^2$, what is the pressure exerted by it now?

6 THERMAL PHENOMENA

You know that when water is heated for some time, it begins to boil and is converted into steam. The steam if allowed to come in contact with a cold surface, condenses to form water again. By sufficiently cooling the water, it freezes to form a solid material—ice. All other liquids also exhibit a similar behaviour. Wax melts when heated and is converted into solid wax again when heat is removed.

6.1 Expansion of Solids, Liquids and Gases

All solids, liquids and gases expand on heating. Do an experiment to verify this. Take a metal ball provided with a hook and suspend it by means of a wire. Now take a small circular ring through which the ball just slips and fix it in a stand as shown in figure 6.1. Lower the ball and put it on the ring. Does the ball slip through the ring? Next, put the same ball over a flame for some time and try to pass it through the ring. Does the ball pass through the ring? If not, why? Has the ball expanded? Is the ring too small now to allow the expanded ball to pass through it? Now keep the ball on the ring for some time. Throw cold water on it from a distance. Do you hear a hissing sound and find steam coming out? Does the ball pass through the ring now? What does this suggest?

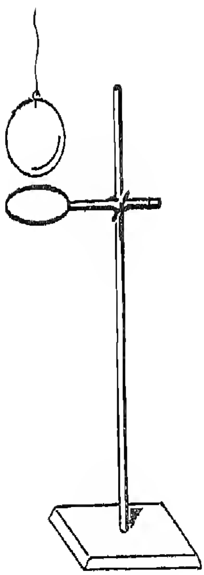


Fig. 6.1

Activity

(1) Take a copper rod and arrange it as shown in figure 6.2. Strongly heat the rod for five minutes with a candle or a Bunsen flame

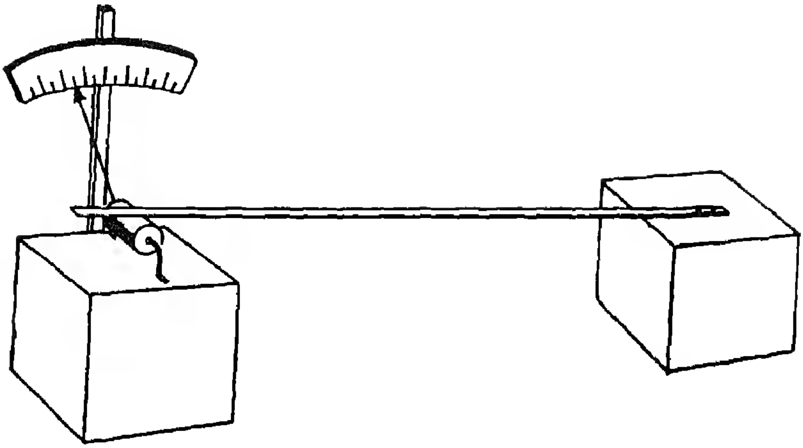


Fig. 6.2

What do you find? You will find that when the rod is heated it turns the roller and thereby moves the pointer. Does this show that the rod has expanded on heating?

(2) Take a bimetallic strip made of two dissimilar metals, say iron and copper fitted with a wooden handle or a piece of

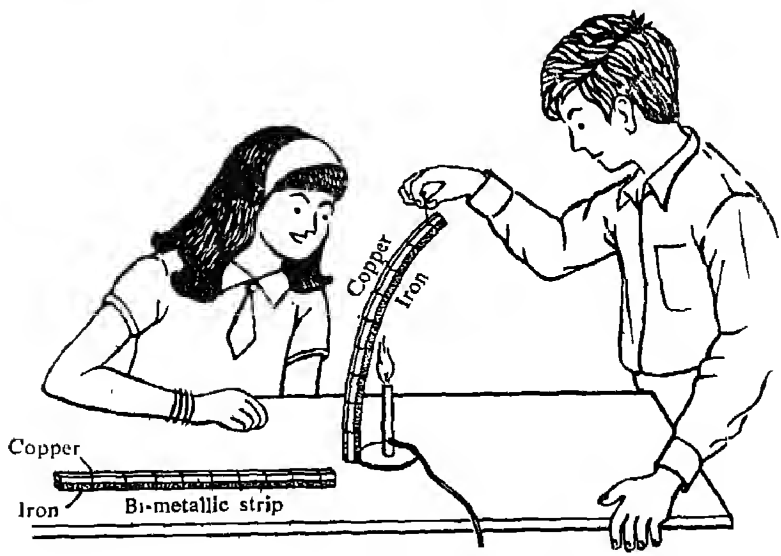


Fig 6.3

thread tied to it (figure 6 3). The strip is straight initially. Now heat it for some time on a spirit lamp. What happens to the strip? In which direction does it bend? Can you tell which metal has expanded more? What would be the shape of the strip in the fixed position as shown in the figure if the iron and copper strips are interchanged? If you immerse the strip in ice cold water, what will be its shape?

(3) Take a nut and a screw (figure 6 4). Note

Fig. 6 4

that the screw passes through the nut. Heat the screw and try to pass it through the nut again. What do you find?

Questions

(1) *Have you seen a gap between two pieces of rails in the same rail line? What are these gaps meant for?*

(2) *How are iron tyres fitted on the wheels of carts?*

(3) *Why does a drinking glass (a thick one) sometimes crack when hot water is suddenly poured into it?*

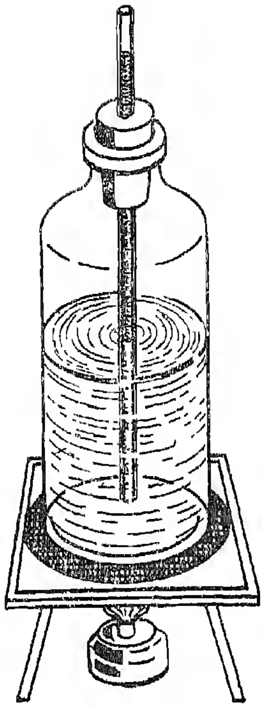


Fig 6 5

Take a small bottle and pour some coloured water in it. Fit it with a cork and pass a tube of narrow bore open at both ends through the cork (figure 6.5). Heat the liquid in the bottle. What do you observe? Does the liquid rise in the tube more and more as you go on heating the bottle? Where has the extra liquid come from? Knowing that you have not added any liquid to the bottle, can you say that the volume of the liquid must have expanded on heating? You will find that water expands as you heat it. Now allow the bottle to cool. What happens to the level of water? You may try to do this experiment with a few other liquids. You will find that they too expand on heating.

Take a round-bottom glass flask with a long narrow tube from its neck (figure 6.6) Dip the tube in coloured water. Some water will rise in the tube. Mark the level of water in the tube. Now rub your hands briskly. Do they become warm? Place them over the flask, or gently heat the flask by holding a candle flame at different places on its outer surface What do you observe? Does the volume of air in the flask expand as indicated by a lowering of the level of the coloured water? Does this experiment show that the volume of gas increases with temperature? Let the flask cool. What happens to the level of water? What does this suggest?

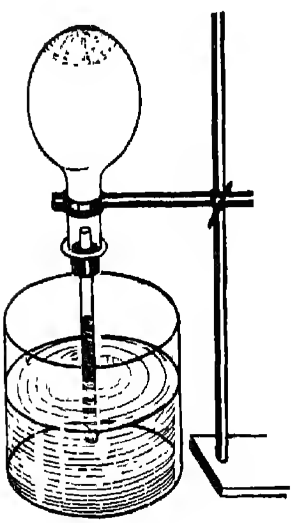


Fig 6 6

Activity

(1) Take a balloon and put it over the neck of a bottle. Immerse the bottle in hot water.

What happens? What is happening to the balloon?

(2) Take an inflated balloon and put it in ice. You will find that it will decrease in size. Does this suggest that air in it has contracted due to cooling?

Question

A glass stopper, when it gets stuck into the neck of a bottle is sometimes heated to remove it. Can you give the reason?

6.2 Temperature

In your daily life you frequently use the words 'hot', 'warm', 'cold' and similar terms. You speak of 'a hot summer day' or of 'a cold winter night'. When you stand in the sun for some time you feel warm, whereas in a shade you feel cool. You often take 'a glass of cold water' or 'a glass of hot milk'. Thus the feeling of cold and warmth on touching an object tells you about its thermal state (i.e. hotness or coldness) in comparison to your body. This quality by which you can compare the hotness or coldness of bodies is called *temperature*. Thus ice is at a lower temperature than your body while boiling water has a temperature higher than that of your body.

Exercise

Arrange the following bodies in order of increasing temperature: (a) a glass of cold water, (b) your body, (c) a block of ice, (d) a kettle of boiling water, (e) a cup of hot tea, (f) a mixture of ice and salt, (g) a kerosene flame, (h) electric bulb, (i) the sun.

The temperature of a piece of red hot coal is more than 100°C and that of a cup of water is less than 100°C but more than 0°C. The mixture of ice and salt is less than 0°C. How can you estimate the temperature of a body? Ordinarily you can tell that a body is hot or cold by touching it. But your sense of touch can often lead you to wrong conclusions. See if this is so

Take three beakers, one containing hot water, the other tepid water and the third cold water (figure 6.7). Dip one of your fingers in the beaker with hot water.

Fig 6.7

Remove the finger and dip it in the beaker with tepid water. What is the feeling that you have regarding the hotness or coldness of water in this beaker? Now dip your finger in cold water and then transfer it to the tepid water. What is your feeling regarding the hotness or coldness of water in this beaker? You find that the water

in the middle beaker in the first case appears to be cold and in the second case it appears hot. Does it not show that your feeling of hotness is relative and depends on the previous conditions of your finger? You find that at first the water in the middle beaker appears to be colder than the hot water in the first beaker, but next it seems hotter than the water in the cold beaker. Thus in the measurement of hotness or coldness, you will have to fix some reference of intensity (degree) of hotness or coldness relative to which you will record the hotness or coldness of a given body. To measure temperature accurately you require a standard 'cold' and a standard 'hot' body. These are melting ice and boiling water. The temperature is measured in a unit called *degree Celsius*, formerly called centigrade and written as °C. The temperature of melting ice is taken as 0°C, while that of water boiling under standard conditions is 100°C. In fact you need a suitable instrument for this purpose. You have already learnt that substances in general expand on heating. This property can be used for providing a measure of temperature.

6.3 Thermometer

Thermometer is an instrument for measuring temperature of bodies. The expansion and contraction of certain substances have been made use of in making such an instrument You have seen earlier how a water-bottle can be used to measure temperature (figure 6.5). Normally water is not used in thermometers. This is due to many disadvantages. Water is transparent and it is difficult to read the level properly. Also, it sticks to the glass surfaces so that when the level of water falls in the tube, it leaves behind some water stuck to the tube and therefore you do not get correct reading. The expansion is also not uniform over a wide range.

6.4 Mercury thermometer

Why of all substances mercury has been preferred for making a thermometer?

The following table gives the normal freezing and boiling points of some of the liquids (under standard conditions):

Liquid	Freezing point in °C	Boiling point in °C
Water	0	100
Mercury	—39	357
Alcohol	-130	78

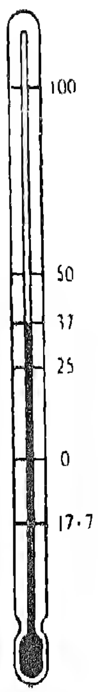


Fig. 6 8

From the table can you tell which of the liquids should be used for a wide range of temperature? You will find that mercury has a wide range of temperature between its freezing and boiling points. In addition, it has several other properties which make it suitable as a thermometric liquid.

These properties are—

(i) It is a shining, silvery white liquid which can be seen very easily from outside the glass tube.

(ii) It does not stick to the glass.

(iii) Its expansion is fairly uniform over a very wide range of temperature.

A mercury thermometer consists of a glass bulb containing mercury, to which is attached a long narrow uniform glass tube which is evacuated and sealed at the

other end (figure 6.8). The thermometer is graduated first by placing it in melting ice (figure 6.9). The level of mercury in the narrow tube is then marked as 0°C. It is heated by steam coming out from a water boiler (figure 6.10). The new higher level of mercury is then marked as 100°C. The length of the tube between these two marks is then divided into 100 equal divisions. Each division then corresponds to 1 degree Celsius (1°C).

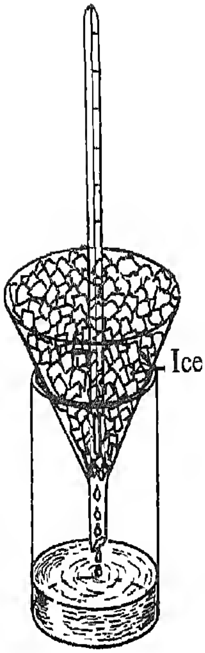


Fig. 6.9

6.5 Celsius and Fahrenheit scales

In the Celsius (centigrade) scale described above, the melting point of ice is marked 0°C and the boiling point of water as 100°C. It is with reference to this scale that you can measure the temperature of any substance. See how you can do it. Suppose you want to measure the temperature of a hot cup of tea. You take a thermometer and dip its bulb in the tea. The mercury in the bulb expands and you find the mercury thread rising up in the bore of the thermometer. After some time the mercury thread becomes steady It no more rises up. Take the reading of the level to which mercury has risen. This reading gives you the temperature of the tea in the cup. Similarly, you can take a cup of water and find its temperature. Now, examine this a little more closely. You have two marks 0°C, and 100°C separated by a certain distance X (figure 6.11). This distance X, corresponds to a temperature difference of 100°C. As in any other measurements, in the measurement of temperature also, you compare an unknown temperature in terms of distance to which the mercury thread rises, say, by h cm, with the distance between 0 and 100 marks, namely X cm. You can, therefore, say that the unknown temperature is $\frac{h}{X} \times 100$°C. In order to avoid

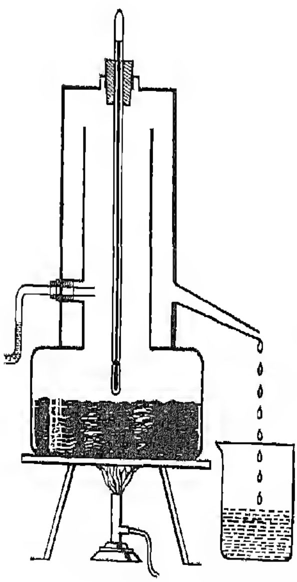


Fig. 6.10

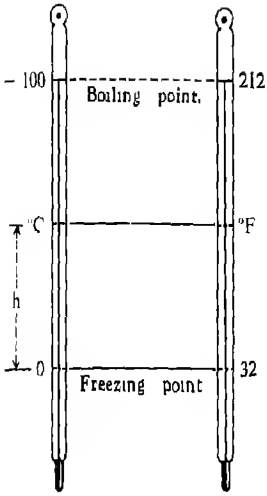


Fig 6.11

Fig. 6.12

the measurement of h and X every time, divide the distance between 0 and 100 marks in 100 equal divisions, so that the distance between any two consecutive divisions corresponds to 1°C. You will find that putting 0°C for the melting point of ice and 100°C for the boiling point of water is completely arbitrary.

Something similar to this was done by Fahrenheit and Romer. In the *Fahrenheit scale*, the melting point of ice is called 32°F and the boiling point of water 212°F as shown in figure 6.11 You can, therefore, find that the same distance between the two fixed points is divided into 100 equal parts on the Celsius scale and each division is called 1°C, whereas in the Fahrenheit scale, this distance is divided into 180 equal parts and the temperature difference as indicated by the two consecutive marks is called 1°F. In the *Romer scale*, the melting point of ice is called 0°R and boiling point of water as 80°R This is not in use now.

6.6 Clinical or Doctor's Thermometer

This is a special type of Fahrenheit thermometer used by doctors to read the temperature of human body. It is very sensitive and quick acting. The capillary tube has got a constriction (figure 6.12) just above the bulb. The stem is short and graduated from 95°F to 110°F. Each degree is divided into five equal parts. So, the fraction of a degree Fahrenheit can be read. To make it sensitive, the capillary tube is made very fine. The bulb is made thin to make the thermometer quick acting. The constriction does not allow the mercury column to fall after it is taken out from the body whose temperature is measured. It has been designed in such a way that mercury column appears magnified when seen from

the front This helps quick and accurate reading of the temperature. The normal temperature of human body is 98.4° F. When you get fever, the temperature is above this normal temperature.

Clinical thermometers in Celsius scale have been devised now. These are replacing the Fahrenheit thermometers. The normal temperature of human body on the Celsius scale is 36.8°C.

6.7 Conversion of temperature readings from one scale into another scale

Sometimes you may require to convert the readings of temperature from one scale into another. How can you do it? You should remember that the same fundamental temperature interval was divided into 100 equal parts in the Celsius scale and 180 equal parts in the Fahrenheit scale. In addition, the zero of the Fahrenheit scale was taken 32 degrees below the zero on the Celsius scale. Hence you get the conversion relation thus,

$$\frac{C}{F-32} = \frac{100}{180},$$

or
$$\frac{C}{F-32} = \frac{5}{9},$$

Therefore $C = 5/9\,(F-32)$.

In the above relation, C is the reading on the Celsius scale and F is the corresponding reading on the Fahrenheit scale.

Exercises

(1) You have two thermometers of the same range whose bulbs have the same volume. In one, the distance between any two consecutive marks is 1 cm, whereas

in the other this distance is half, i.e. 0.5 cm. Do these readings convey any information about the diameters of the bore? If in the former, one division corresponds to a temperature difference of 1°C, will the latter correspond to a temperature of 0.5°C or 2°C?

(2) Heat produces some changes in a substance Name the changes on which a thermometer can be devised. What change or changes of a substance is made use of in a mercury thermometer?

(3) What do you mean by the fixed points of a mercury thermometer? What temperatures do they stand for in the—

(i) Celsius scale,

(ii) Fahrenheit scale,

(iii) Romer scale.

(4) The normal temperature of human body is 98.4°F. What is it in the Celsius scale?

(5) Convert,—

(i) 20°C, 40°C, 80°C into temperatures on the Fahrenheit scale,

(ii) 182°F, 92°F, 68°F and 113°F into temperatures on the Celsius scale.

(6) The readings with a Celsius and a Fahrenheit thermometers of a substance are the same. What is the temperature? At what temperature the reading of a Fahrenheit thermometer will be double that of a Celsius thermometer?

(7) (i) Liquid nitrogen boils at—196°C. What is the reading on the Fahrenheit scale?

(ii) During a thunderstorm, the temperature dropped by 15°F. What is the drop in °C?

7 WAVE MOTION

7.1 Waves

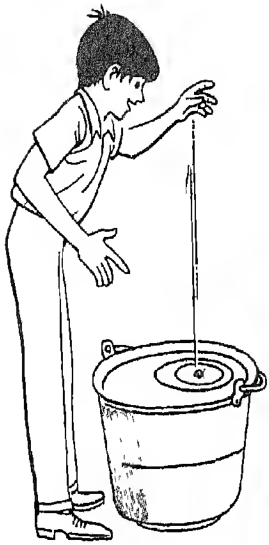


Fig. 7.1

If you drop a stone in a pool of water, circular waves will be found on the surface (figure 7.1). The waves can be seen moving away from the source. Falling drops of rain on puddles or on any water surface cause the same pattern of waves. The same thing happens when a pencil is dipped in a tray filled with water (figure 7.2). These waves start from the

Fig. 7.2

place of disturbance and spread out in all directions like expanding rings. You can even generate lines of waves in a tray by touching the water surface with a pencil or a scale along its length (figure 7.3). The waves appear to start from a line where the water surface has been disturbed and move in a direction perpendicular

Fig 7.3

to the line of disturbance. As the waves move away from the source, the waves gradually lose their height and ultimately die away.

Question

Do the waves, you have seen just now, move with a definite velocity?

Fig. 7.4

You may have seen waves in a paddy field when the wind blows over them. Ripples form in the cup if you blow on the tea in it (figure 7.4). When the national flag flutters with breeze high up on a building's top, waves are formed on it (figure 7.5).

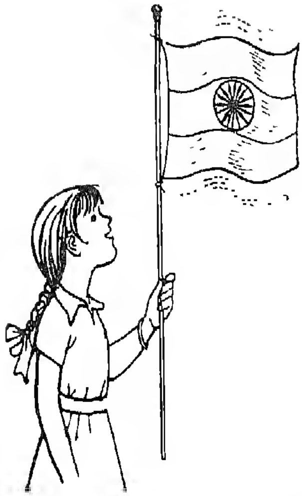


Fig 7.5

On a tray filled with water, drop little pieces of paper. Let them float. Dip a pencil so that gentle waves appear on the surface. Every paper piece will move up and down, remaining practically at its own place. The waves seem to travel but actually the water does not move away with the waves. Like all substances, water also consists of molecules. Water molecules on the surface move up and down practically at the same place as the waves appear to move forward.

Look at the ripple tank (figure 7 6). It consists of a glass tank. Small waves or ripples are formed in the

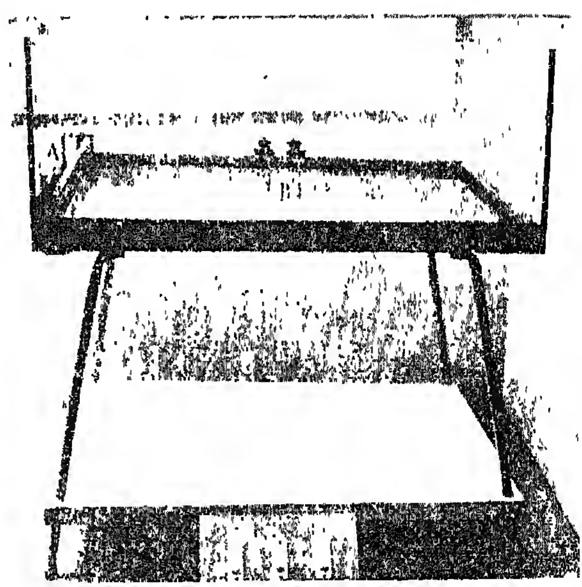


Fig 7.6

water of the tank either by vibrating a flat metal plate A situated on the left side of the tank or by one or more spherical balls or discs B shown in the middle. In both the cases the vibrator is excited with the help of a dry cell. When the flat plate is used you get waves which are

Fig. 7.7

parallel to the rod (figure 7.7), whereas when spherical balls are used, you get circular waves (figure 7.8)

Fig. 7.8

These waves can even be projected on a paper placed below the tank. When the tank is illuminated from above by a source of light, you get alternate dark and bright images on the paper.

Watch the waves you have made in the tray or in the ripple tank. The top of a wave is called a *crest* and the bottom a *trough* (figure 7.9). In any wave motion,

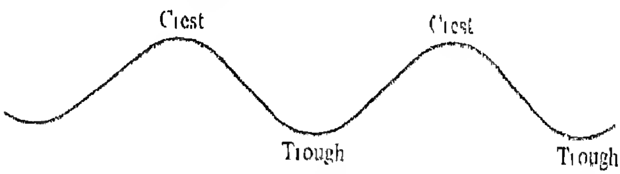


Fig. 7.9

crest and trough follow one another and move in the direction of motion of the wave. The distance between two successive crests or two successive troughs is called one *wavelength*.

Activity

(1) Take water in a tray and pour an extra drop of water from a dropper (figure 7.10). What happens now?

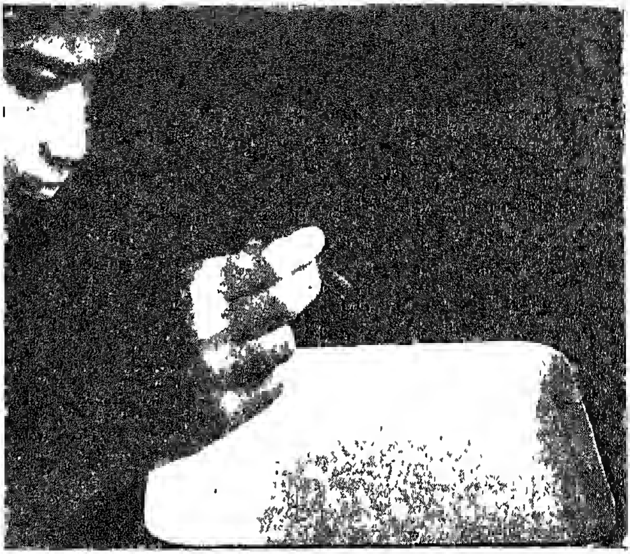


Fig 7.10

(2) Float a small rubber or a plastic ball in the water and press it (figure 7.11). Do you get a

Fig 7.11


Fig 7.12

wave pattern? Examine the crests and troughs carefully. Guess how high the crests are Are the heights the same all over? Float a rectangular piece of wood in water of the tray Press it down and release immediately (figure 7 12) What is the pattern of the waves? Do the waves come back after hitting the opposite wall of the tray?

(3) Take a long string, about 5 meters in length, and lay it on the ground Hold one end of the string and give a single jerk sideway (figure 7 13). Do you see a hump moving from

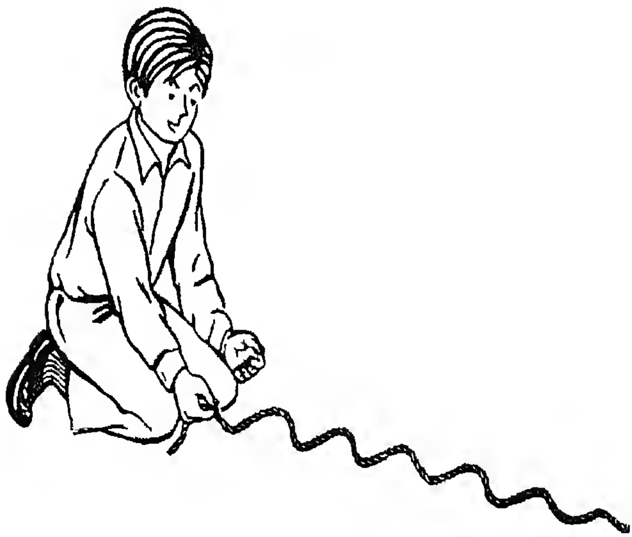


Fig 7.13

one end of the string to the other? Such a hump is called a *pulse* Now give a single jerk to the string towards the right. You see a pulse to move along the string and call it a positive pulse (figure 7.14a). Then give a single

jerk towards the left Again you see a pulse moving along the string. This is a negative pulse (figure 7 14b). The different points on the string are displaced in opposite directions, in these two pulses

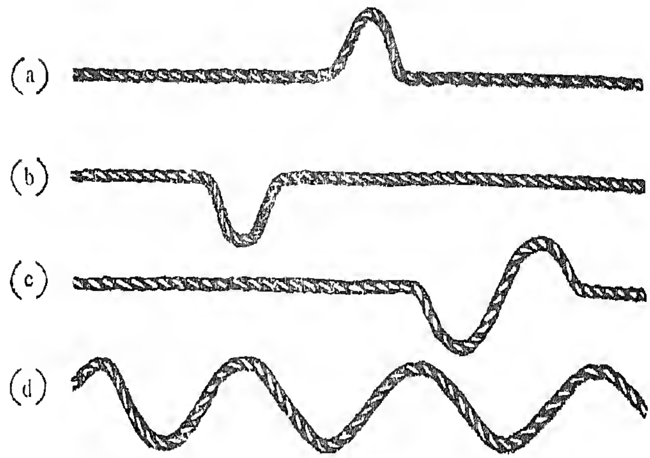


Fig 7 14

If a jerk is given to the right followed by another to the left, a positive pulse followed by a negative pulse will be seen moving along the string (figure 7.14c). If jerks are given to the right and left in quick succession, a train of positive and negative pulses moves along the string. Such a train forms a wave (figure 7.14d). The positive and negative pulses are like crests and troughs of waves on water surface. The disturbance created by the jerks at one end of the string travels to the other end along its length. The wave seen on the string is, therefore, called a *progressive wave.*

Question

Does the string itself move with the pulses?

Activity

Put an ink mark on the string Repeat the experiment. Observe the motion of the mark. Does the mark move along or perpendicular to the string?

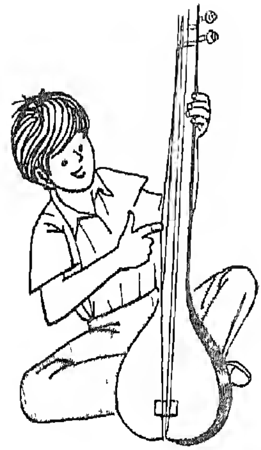


Fig 7 15

Since each particle moves up and down, perpendicular to the direction in which the wave travels, it is called a *transverse* wave. You can find this type of wave in strings. If you pluck the string of a 'Tanpura' or a 'Sitar', the string of the instrument vibrates in the same way (figure 7.15). You will also learn in future that light, heat and radio waves are transverse waves

Questions

(1) *What type of waves do you expect when the membrane of a 'Tabla' is excited?*

(2) *Place few pieces of beads on the top surface of a small table and strike the table top with a hammer. What happens to the beads and why?*

Activity

Take a coiled spring and hang it horizontally as shown in figure 7 16 Compress a few loops at one end of the spring and then release them You will find that the compression moves back and forth from one end of

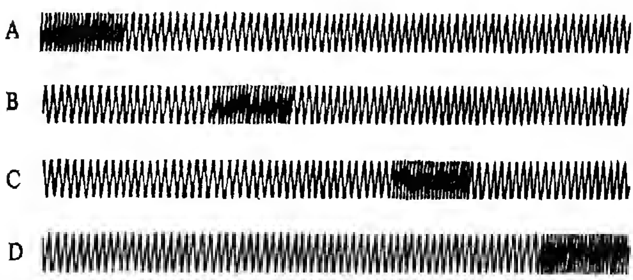


Fig. 7 16

the spring to the other. You will have similar experience when one end is struck with a hammer. This compression of the loops which started at one end on the spring travels along its axis. You will find that these loops move to and fro along the length The loops do not always keep the same distance among themselves In some places they are very close to one another while in some other places they are far apart The place where the loops are very close is the position of *compression* and the place where they are far apart is the position of *rarefaction* Notice that the compression and the rarefaction are not localised at particular places but travel along the length.

These are *longitudinal* waves. Sound waves are examples of this type. Here the particles of a medium move in the direction of wave travel. In a sound wave the air particles move in the direction of waves. This to and fro motion of air particles produces compressions and refractions in it which actually move through the medium. You have noticed before how compressions move through a coiled spring. In figure 7.17 you will find how these air particles come together at one place and spread out at another.

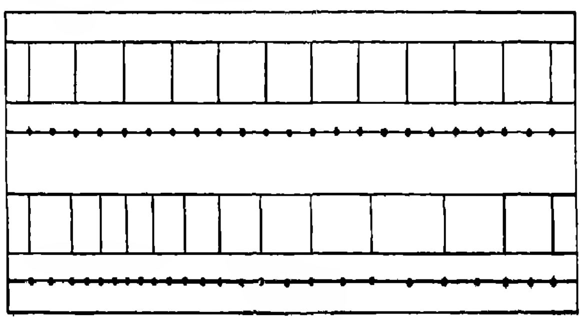


Fig 7.17

Activity

Fasten one end of a rope to a strong iron rod or the bar of a window and hold the other end with both hands. Ask some one to strike the rod or bar along its length with a hammer at the position where it is fastened (figure 7. 18). Do you feel a kind of sensation in your hands? What it is due to?

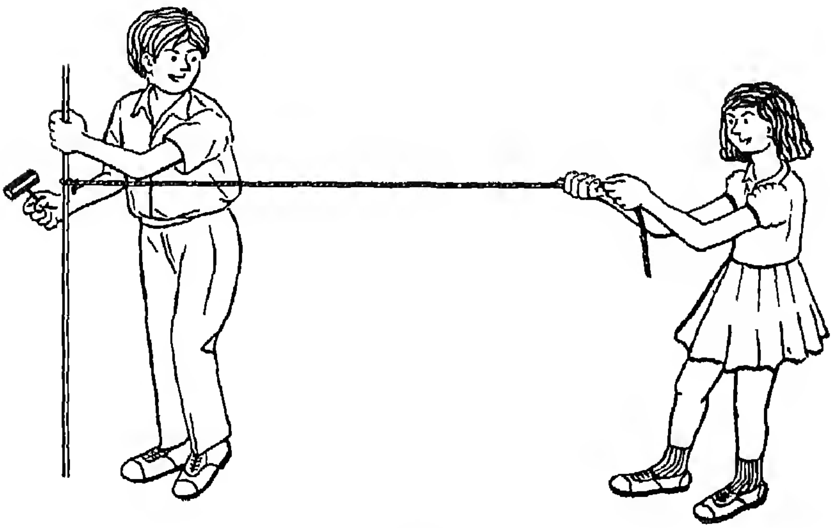


Fig 7.18

Question

A long coiled spring suspended from two horizontal bars is hung horizontally with both the ends of the spring free (figure 7.19). Excite longitudinal waves at one end. What happens to these waves if the other end is now kept fixed?

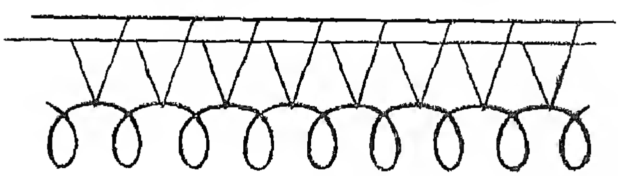


Fig. 7.19

7.2 Waves carry energy

When you drop a stone in a pool of water, part of the kinetic energy of the stone is transferred to the water at the point of disturbance and the waves which are generated on the water surface carry energy with them. As the waves move, the energy carried with them spreads over a larger region. As a result, the height of the waves which depends on the amount of energy carried by the waves gradually decreases and ultimately dies away.

Fig 7 20

Activity

Place a toy boat or a piece of cork floating in the water of a tray. How can you set the boat in motion without touching or hitting it? Stir the water or drop a pebble near the boat (figure 7.20)? See that it moves. From where does the boat get its energy of motion?

All types of waves i.e. heat, light, sound and radio waves carry energy. When a body vibrates giving out sound, it transfers its energy to the neighbouring air particles which move forward and backward. These particles, in course of their vibration, come close to the next layer of particles, collide with them and transfer their energy (figure 7.21). The particles vibrating next

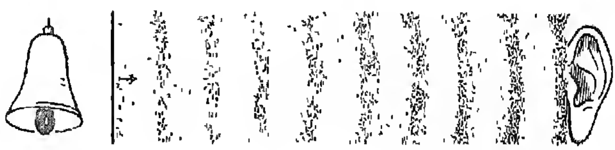
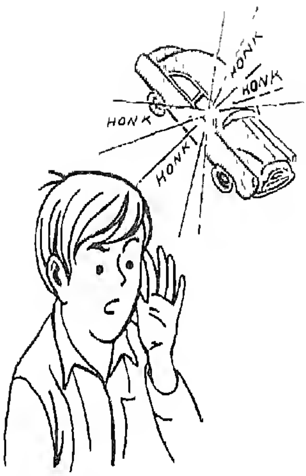


Fig. 7.21

repeat the same process. Thus when a sound wave moves, it carries energy with it. The sound wave on

coming in contact with your ear, puts your ear-drum into vibration. As a result you hear a sound. Energy from a source of light strikes the retina of your eyes and creates the sensation of vision.



Questions

(1) *When light of the sun reaches the earth, what type of energy does the earth actually receive?*

(2) *When you hear a car horn what type of energy is received by your ear?*

7.3 Properties of a wave

Look at the waves carefully when you excite them in a pool of water. You will find that the waves have several distinct features.

You can notice that the waves move with a velocity. You can define velocity as the distance through which the waves move in one second The velocity of waves depends on the medium through which it moves. The velocity of light in vacuum is 3×10^8 m/s. The velocity of sound in air under ordinary conditions is about 330 m/s. The velocity of sound depends on the nature of the medium. For example it travels faster in water than in air.

Questions

(1) *Waves are produced due to the motion of the particles of the medium. Is the velocity of the particles of the medium different from that of propagation of waves?*

(2) *Can you suggest a method for finding the velocity of sound?*

Another important feature of waves you will notice is the height of a crest or a trough from the undisturbed position. This is called its *amplitude*. In figure 7.22 AB, CD, EF and GH are amplitudes and XY indicates the undisturbed position of the water surface. The amplitude of a wave is expressed in units of length.

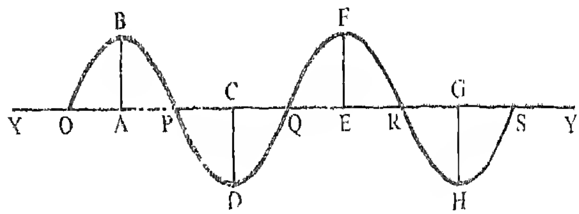


Fig 7.22

Another feature of a wave is its wavelength. The distance between two successive crests or successive troughs is called *wavelength*. In the figure 7.22 the distance BF or DH is a wavelength. The wavelength is also measured in units of length. The wavelength of light wave is very small and is expressed in angstrom units ($1Å = 10^{-10}$m). The wavelength of radio waves is large and it is usually expressed in metres.

One complete up and down movement of a particle, is called one *cycle* of the wave. One cycle produces one crest and one trough. In the same figure OQ, QS, PR are each one cycle. When the waves travel the number of wave cycles that cross a point in one second is called its frequency. If 1 complete cycle passes over a point in one second then the frequency is given as 1 Hertz (Hz) i.e. 1 cycle/second. Frequency can also be determined by dividing the total number of wave cycles created in a certain interval of time by the time in which these waves are created and is equal to the number of vibration

which the source makes in one second. If 'N' is the number of the wave cycles produced in the time 't' then the frequency 'n' is expressed as

$$n = \frac{N}{t} \text{ Hz}$$

7.4 Relation between velocity, wavelength and frequency

Frequency, wavelength and velocity of wave motion are related to one another. This relation is true for all types of waves. Since frequency is the rate at which waves are produced in one second and wavelength is the length of a single wave, the product of frequency and wavelength is the distance through which a wave travels in one second. If the velocity of the wave is expressed by v, frequency by n and wavelength by λ (lambda) then $v=n\lambda$, that is velocity=wavelength $\times$ frequency.

If the length of a wave is 1 cm when frequency is 10 Hz then the velocity of the wave is 10 cm/s. Note that the velocity of a wave in a medium is constant. If the frequency is doubled but the velocity does not change then the wavelength becomes half and the product $n\lambda$ is still the same.

Exercises

(1) A single wave travels along a rope of 100 cm length in 5 seconds. What is the velocity of the wave?

(2) A radio station broadcasts on a wavelength of 500 metres. If the speed of the radio waves is 3×10^{10} cm/s, calculate the frequency of the station in k Hz.

(3) Calculate the frequencies of the following radio stations.

Station	**Wavelength**
Bombay	41·44 m
Calcutta	300·00 m
Delhi	89·15 m
Madras	416·07 m
Nagpur	508·50 m

(4) An oscillating particle has a period of 0.025 second. How many vibrations does it make per second?

(5) A source producing waves has a frequency of 480 Hz. The waves travel in air with a speed of 348 cm/s. Find the wavelength.

(6) A sitarist produces a note of frequency 256 Hz and if the velocity of sound is 330 m/s, what is the wavelength of the wave?

(7) Fix a wire as shown in figure 7.23. Adjust the distance between the two bridges. Pluck the string and you

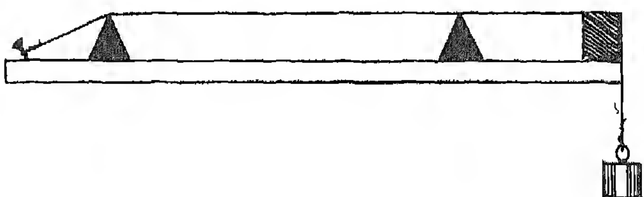


Fig 7 23

produce sound. Now change the length between the bridges and pluck the string again Is there any difference in the sound now? Continue to change the length between the bridges. Can you infer any correlation?

7.5 Reflection

Activity

Place a tray on the table and fill it up with water. Touch the surface of water with the tip of a pencil. What pattern do you get circular or linear?

Place a strip of metal block in the tank so that its top projects above the surface of water. What happens to the waves when it meets the metal surface? Generate a series of circular waves as you did earlier. You can do the same with the help of a pencil, or a metal rod. You can also excite waves in a ripple tank Do the waves stop at the wall of the metal block or bounce back? If the waves bounce back, how do they look? Look at figure 7.24 The wave approaching the metal surface is

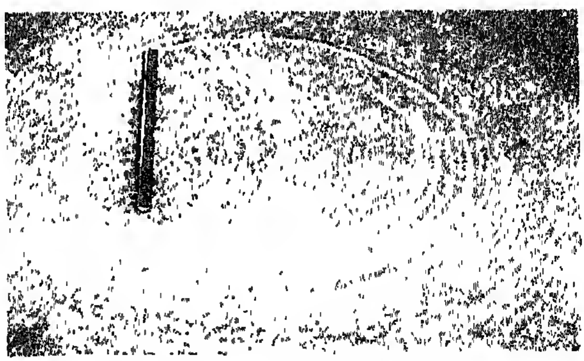


Fig. 7.24

called an *incident wave*. The same wave when it bounces back from a surface is called a *reflected wave*. This process of bouncing is known as *reflection*. Note the directions of incident and reflected waves.

What is the nature of the curve after reflection? Is it an arc of a circle? Where do you expect its centre to lie?

7.6 Refraction

So long you have seen a pulse of waves moving in the same medium. What happens to this pulse when it moves from one medium to another? Do an experiment to get your answer

If you have observed waves in a pond or a river you will find that the waves crowd together and move more slowly as they approach the shore This is because they move from deep to shallow water. In the case of waves on the surface of water, the speed depends on the depth of water. Therefore water of two different depths may be considered as two different media.

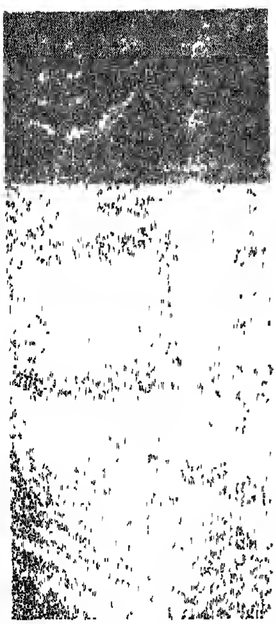


Fig 7 25

Activity

Take water in a tray and place inside it a small rectangular glass plate smaller in size than the bottom of the tray Notice that the glass plate is covered by a very thin layer of water This creates two different media. Excite straight waves in the water What do you find? The waves move slowly and crowd together in shallow water (figure 7 25). The waves bend at the surface of separation of the two media You will get reverse effect if you excite waves in the shallow water and look at the waves in deep water.

Excite circular waves again and see that the waves show same effect as before (figure 7.26).

Fig 7 26

You find that a wave not only changes its speed but also its direction as it crosses the boundary of the two media. This bending of waves at a boundary is called *refraction.*

When a wave crosses the boundary of two media its velocity changes but the frequency remains the same. As a result wavelength changes on crossing the boundary.

Let v_1, v_2 and λ_1 λ_2 be the velocities and wavelengths of the waves on either side of the boundary and n the frequency. Then

$$n\,\lambda_1 = v_1$$

and $$n\,\lambda_2 = v_2$$

Therefore $$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}\ .$$

Notice that the ratio of the two wavelengths is equal to that of the two velocities. This ratio is called the index of refraction and denoted by the Greek letter μ.

Questions

(1) *What happens when two waves in a string move in opposite directions and meet each other?*

(2) *What happens to a wave when it passes through a narrow slit?*

7.7 Different kinds of Waves

Earlier you have learnt about the behaviour of waves. You come across numerous kinds of waves in your daily life Here you will learn about some of them.

(a) Waves on water

If you disturb the surface of water gently, the tiny waves that are formed on it are known as *ripples*. Their wavelengths are less than 2 cm and their speed is about 20—25 cm/s. When the sea is disturbed huge waves travel on its surface Their wavelength may be as large as 5 meters or even more and they travel with a speed of about 3 m/s. You will see that both these waves are of transverse type and both travel on the surface of water. However, the speed of ripples depends upon the surface tension of water while that of seawaves is governed by gravity and hence their speeds are different.

(b) Sound waves

Whenever a sound wave travels in air, the particles of air move to and fro in the same direction in which the wave travels. This motion of the particles gives rise to compressions and rarefactions which form a longitudinal wave.

Activity

(1) Fix one end of a blade or a strip of metal in the crevice of a table and pluck the other with your finger Do you hear a sound? While the blade is vibrating touch it with your finger Do you feel the motion of the blade? As the blade moves forward, the air in front is compressed. When the blade moves backwards,

the air in its front gets rarefied. These compressions and rarefactions travel in all directions. The speed of sound waves in air is 332 m/s at 0°C and 347 m/s at 25°C.

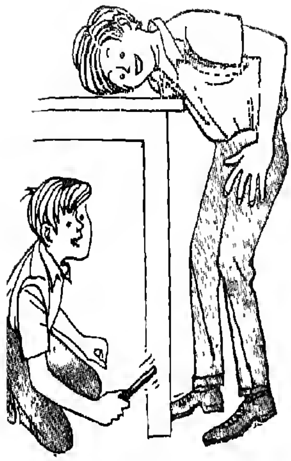


Fig 7.27

(2) Place your ear in contact with the surface of a table (figure 7.27). Let another boy rub the foot of the table with a nail or an iron rod. Can you hear the sound? Now take your ear off from the table. Do you still hear the sound? You will observe that you can hear the sound better if you put your ear to the table. Thus you will see that sound waves can travel in solids also.

The speed of sound waves in wood is nearly 4500 m/s. They travel in iron at a still faster speed, namely 5000 m/s. They travel in water rather slowly with a speed of about 1400 m/s.

The sounds you can hear have frequencies between 30 and 20000 vibrations per second. However, these limits change from person to person and also with age. This range is known as audible range. Dogs are able to hear sounds above a frequency of 20000 Hz. Bats produce sounds having frequencies of about 50000 Hz and they can also hear them. As the wavelength of sound of this high frequency is very small, the sound produced by bats is reflected by small obstacles that may lie in the path of their flight at night. This is how bats can steer its course at night. Sound waves with frequencies higher than 20000 Hz i.e. beyond the limit of human audibility (hearing) are known as ultrasonic waves.

The musical scale of the middle octave Sā, Re, Gā, Mā, Pā, Dhā, Ni, Sa in Indian music have frequencies 240, 270, 301.4, 320, 360, 405, 450 and 480 respectively in Hz.

When the wire of a sitar or a sarod is plucked, the disturbance travels as a transverse wave on the wire but the waves produced in air by the vibrating wire travel to you as longitudinal waves.

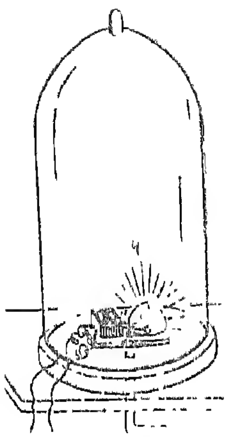


Fig 7.28

You should note that sound cannot travel in vacuum. If an electric bell is kept ringing inside a bell jar (figure 7.28) and if the air in the bell jar is removed with a vacuum pump, the sound of the bell is not heard. In this case, though the surface of the gong of the bell vibrates, the disturbance is not communicated to the surroundings as there is no air to carry the disturbance

(c) Seismic waves

You have heard about the earthquakes and how they cause havocs. The earthquakes are caused by a disturbance somewhere inside the earth. The disturbance produces waves which travel through the earth. As a result of this, the surface of the earth vibrates Both the types of waves, longitudinal as well as transverse, are produced during earthquakes. The longitudinal waves are known as primary waves and they travel with a speed of 8 km/s. through the earth. The transverse waves are known as secondary waves and these travel with a speed of 5 km/s. This difference in the speeds of the two waves is used in determining the distance of the source of the earthquake from the observer. This source from where the disturbance originates is called *epicentre*.

(d) Radio waves

Have you listened to the announcement of a radio station before a programme begins? The wavelength announced tells you that the station generates and sends radio waves having that particular wavelength. The various medium wave stations send their programmes on wavelengths between 200 m. and 550 m You must have also noticed that a large number of distant radio stations broadcast their programmes on wavelengths between 10 m and 80 m. The radar, which is used to locate distant objects like aeroplanes, uses wavelengths between 3 and 10 cm. These waves are known as microwaves

You see, therefore, that the above radio waves have wavelengths ranging from 1 cm. to several metres. These radio waves are produced at the transmitter by creating electric and magnetic disturbances in space.

(e) Light

Light is also similar to radio waves. White light contains waves of different wavelengths The different wavelengths, can be separated from one another The colours in a rainbow arise as a result of the separation of sunlight into different waves. The waves of violet colour have a very small wavelength $\frac{4000}{100000000}$ cm or 400 nanometers (nm) or 4000 angstrom units (Å). Waves of red colour have a wavelength 750 nm, about twice that of violet colour.

(f) Infrared and ultraviolet rays

The heat coming from a furnace also arrives in the form of waves. Their wavelengths range from the lower

limit of radio wavelengths upto 800 nm. Thus they have wavelengths lying between those of radar waves and waves of red colour. They are called infrared rays and are not visible Similarly, there are waves having wavelengths smaller than those of violet light. They are known as ultraviolet rays. They are also not visible and their wavelengths lie between 400 nm and 100 nm.

(g) X-rays

You are probably familiar with X-rays which are used to take photographs of bones inside the body. They are also known as Roentgen rays after their discoverer Their wavelengths are shorter than those of ultraviolet rays and lie between 100 nm and 0.01 nm.

(h) Gamma-rays

There exist waves which are even more penetrating than X-rays and are called gamma rays They are produced in some nuclear transformations about which you will learn at a later stage. They are also present in cosmic rays which strike the atmosphere of the earth continuously from space The wavelengths of gamma rays are less than 0.1 nm.

The work of Faraday, Maxwell and Hertz has shown that radio waves and light waves are essentially similar. Today you know that radio waves, heat rays i.e infrared rays, visible light, ultraviolet rays, X-rays, gamma rays are all of the same nature. They are all electromagnetic waves. They only differ in their wavelengths or frequency. All of them travel in vacuum with a speed of 3×10^8 m/s. The fact that you receive light from the sun and the stars, which has travelled through space shows that these waves can travel in vacuum also.

While waves such as sound waves and seismic waves require some material medium for their propagation, the electromagnetic waves do not need any material medium.

Exercise

(1) Prepare table giving the following details of different waves.

Kind of wave	Medium	Nature (Transverse or longitudinal)	Speed	Fre-quency	Wave-length

(2) Calculate the frequencies for the light of the following wavelengths seen in the spectrum of hydrogen atoms and plot a graph showing wavelength against frequency

656 2, 486.1, 434.0, 414.1 nm.

(3) Complete the following sentences:

(a) A wire of a sitar is plucked.

(i) The waves produced ~~on~~ the wire are............

(ii) The waves produced in the air are ....

(b) Sound waves travel faster in. . .....than in water.

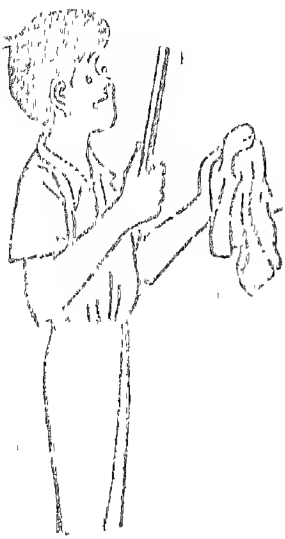
(4) Write down the following media in the order of speeds of sound in them—Water, Air, Iron, Wood.

(5) Match the wavelengths in group A with the waves in group B

Group A	Group B
(1) 10 nm	(1) Radiowaves
(2) 0·01 nm	(2) X-rays
(3) 500 nm	(3) Gamma rays
(4) 100 nm	(4) Visible light
(5) 500 nm	(5) Ultraviolet rays.

8 COULOMB'S LAW, ELECTRIC FIELD AND ELECTRICAL POTENTIAL DIFFERENCE

8.1 Coulomb's Law



You have learnt that when two bodies such as a glass rod and a piece of silk cloth are rubbed together, each acquires an electric charge. The glass rod acquires a positive charge and the silk cloth gets an equal negative charge. You have also learnt that two like charges repel each other, whereas two unlike charges attract each other. The first investigation about this electrostatic force was done by Charles Coulomb (1736-1806). He found that the force of attraction or repulsion between two charges varies directly as the product of the magnitude of each charge and inversely as the square of the distance between them. Suppose the symbol 'Q' stands for the charge on a body. The charges on two bodies can be written as Q_1 and Q_2. If 'F' denotes the force, then

$$F \propto Q_1 \times Q_2$$

If 'd' denotes the distance between the two charges, then 'F' depends on 'd'. It is found that

$$F \propto 1/d^2.$$

Even if the charges are the same and the distance between them is also the same, the force between the charges depends upon the medium between the two charges. The above facts can be combined as $F = K \dfrac{Q_1 \times Q_2}{d^2}$, where K is taken as a positive constant.

Thus the force between two point charges is proportional to the product of the two charges and is inversely proportional to the square of the distance between the two.

This is known as the *Coulomb's Law* and the force acting between the charges is called the *Coulomb's force.*

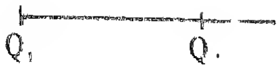


Fig 8 1

The direction of the force is along the line joining the charges (figure 8.1).

If Q_1 and Q_2 be both positive, then the expression $\frac{Q_1 Q_2}{d^2}$ will be positive.

You also know that in this case the charge Q_1 repels Q_2, i.e. the force on Q_2 is in the direction $Q_1 Q_2$. Thus a positive value for the force denotes a force of repulsion.

Now if Q_2 be negative (while Q_1 remains positive), then the expression $K\frac{Q_1 Q_2}{d^2}$ will be negative. A negative force along $Q_1 Q_2$ means an effective force along $Q_2 Q_1$. In this case Q_2 is attracted towards Q_1. Thus a negative value for the force denotes a force of attraction.

The value of the constant K in the Coulomb's law depends upon the units in which the force F, the distance d and the charges Q_1 and Q_2 are measured and the medium in which they are placed. You know that the smallest charge found in nature or the elementary charge is the charge of an electron and that all other charges are integral multiples of this charge. Thus you can measure any charge in terms of the electronic charge. If you take Q_1 and Q_2 both in terms of electronic charge, measure F in Newtons and the distance d in metres, the constant K has the value

$$K = 2.3 \times 10^{-28} \frac{N.\ m^2}{(\text{electronic charges})^2} \text{ for vacuum.}$$

Thus, if $Q_1 = n_1$ elementary charges and $Q_2 = n_2$ elementary charges, where n_1 and n_2 are integers, the Coulomb's law can be written as

$$F = 2.3 \times 10^{-28} \frac{n_1 \times n}{d^2} \text{ Newtons.}$$

In practice, it is seen that the charge on a body is very large as compared to an elementary charge. For convenience, therefore, a larger unit of charge is used. This unit is called *Coulomb* and is equal to 6.25×10^{18} times the charge of an electron. This unit is denoted by 'C'. Therefore, the charge of an electron is 1.6×10^{-19} C. When the charges are measured in Coulomb you get for vacuum

$$K = 9 \times 10^9 \frac{N.\,m^2}{C^2}.$$

and the Coulomb force,

$$F = 9 \times 10^9 \frac{Q_1 \times Q_2}{d^2} \text{ Newtons.}$$

In the above equation F is in Newtons, Q in Coulombs and d in metres.

Questions

(1) *What will be the force between two electrons separated by a distance of 0 1 mm if the charges are measured in Coulomb, the distance in metres and the medium is vacuum?*

$$(K = 9 \times 10^9 \frac{N.m_2}{C^2}).$$

(2) *What will be the force between an electron and a proton separated by a distance of 0.5 Å?*

8.2 Range of Coulomb Force

The Coulomb's law tells how the force between two charges changes when the distance is changed. Does this relation put any limit on the distance between the two charges? There is no limit to the value of the distance at which this law is true. The distance may be large as in the case of two charged clouds or very small as in the case of an atom where the positive charge on the proton and the negative charge on the electron are separated by a distance of about 10^{-10}m.

8.3 Coulomb's Force and Gravity

The Coulomb relation shows that when two charged bodies are very close to each other, the force between them is quite large even when the charges are small. This is clearly seen from the experiment with paper bits. Paper bits are pulled by the earth. This pull towards the earth is due to gravity. A small paper bit of approximate mass 1 mg is pulled by a force of about 10^{-5} N. When a charged glass rod is brought near paper bits, they move towards the glass rod. Thus the Coulomb force due to the charge on the glass rod must be larger than the gravitational force. The charge on the glass rod is about 10^{-9}C. Thus, a very small charge of this value produces a large force—much larger than the force of attraction between a huge body like the earth and one paper bit.

Question

What are the similarities and differences between Coulomb force and gravitational force?

Exercises

(1) Two pith balls are suspended one metre apart. Each is given a charge of one Coulomb. How much force will act on each of them?

(2) Two protons are 1mm apart. One of them is fixed and the other is free to move. What will be the acceleration of the free charge? (Mass of a proton is 1.6×10^{-27} kg, the charge of a proton is the same as that of an electron).

(3) If 1 $\mu C = 10^{-6} C$, find the force between a positive charge of 100 μC and a negative charge of 50 μC placed half a metre apart. Is the force attractive?

(4) Two like charges, each of 0.01 C and placed in air repel each other with a force of 9×10^{3} N. Find the distance between the charges. (K for air may be taken the same as for vacuum).

(5) The tip of a plastic rod pulls bits of paper with a force of 0.1 N when held at a distance of 1 cm. Find the charge on the tip of the rod. (The charge produced on the paper bits is equal to the charge on the rod).

8.4 Electric Field

If you place an isolated charge $+Q$ at a point P, it exerts a force on any other charge placed in the surrounding space. The surrounding space in which the charge exerts its force is called its *electric field*.

8.5 Further discussion of Coulomb's law

You have so far seen that if there are two charges separated by a distance, then they will always experience

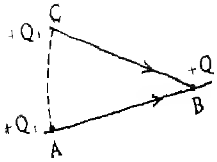


Fig 8.2

a mutual force according to Coulomb's law. Imagine two similar charges Q_1 and Q_2 placed at A and B (figure 8.2). From Coulomb's law, there will be a force of repulsion on Q_2 due to the charge Q_1. This force F_1 will be,

$$F_1 = K \frac{Q_1 Q_2}{AB^2} \text{ along AB.}$$

If now the charge at A moves over to C, then the force on the charge Q_2 at B will be,

$$F_2 = K \frac{Q_1 Q_2}{CB^2} \text{ along CB.}$$

Thus, as the position of the charge Q_1 changes from A to C, the force experienced by Q_2 changes in direction as well as in magnitude. How fast does the charge Q_2 respond to the movement of the charge Q_1? It has been found that the charge Q_2 responds to the movement of the charge Q_1 after a certain time which has been found to be equal to the time required for light to travel from A to B. You can take an example to understand this point. Two corks are floating on water in a trough. If the corks are touching each other and if one of them is disturbed (figure 8.3), it is found that the other cork follows the motion instantaneously. If the two corks are separated by a distance, and if one of the corks is disturbed, a certain time elapses before the other cork follows the motion (figure 8.4). This is the time required for the disturbances to travel from one cork to the other, after which the second cork starts to move. A similar thing happens in the case of electric charges. The charge Q_1 produces a field in the surrounding space. The charge Q_2 interacts with this field after a very small time.

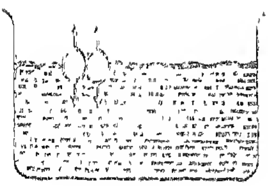


Fig 8.3

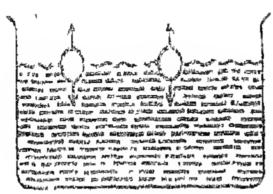


Fig 8.4

The mutual force between two charges Q_1 and Q_2 can be pictured as a result of two processes,—

(i) the creation of an electric field in the surrounding space of Q_1 and (ii) the influence of this field on the charge Q_2.

Since the force between the charges is mutual, the charge Q_1 is also placed in the electric field of the charge Q_2 and experiences a force due to the field of Q_2. The electric field around the charged body Q_1 exists even when no other charged bodies like Q_2 are placed in its vicinity. However, to observe the effect of the electric field at any point in space, one has to bring another charge called a *test charge* at that point.

8.6 Electric Intensity

The magnitude of the electric field or electric intensity at any point is defined as the force experienced by a unit positive test charge placed at that point. It is assumed that the introduction of the test charge does not alter the field already existing there. The smallest charge is an electronic charge. Hence, the magnitude of an electric field at any point can be defined as the ratio of the force experienced by an electron placed at that point to the charge of an electron in coulomb. By convention, test charges are taken to be positive.

If a test charge q experiences a force F at any point, the magnitude of the electric field or its intensity E at that point is given by

$$E = \frac{F}{q} \frac{\text{Newton}}{\text{Coulomb}}.$$

This is the force that a unit positive charge would have experienced at that point. This means that the force exerted on a charge q at a point where the electric intensity is E is equal to q times E. It is evident that the electric field is a vector quantity having both magnitude and direction *The direction of an electric field at any point is the direction of the force that a positive test charge would experience at that point and its magnitude is equal to the magnitude of the force experienced by a unit positive charge.*

If the test charge is negative, as an electron, then the direction of the electric field vector E is opposite to the direction of the force experienced by the negative test charge. The electric field vector at any point is referred to by several names, e.g., electric field strength, electric field intensity or simply field intensity.

In the MKSA system of units, since the forces are measured in newtons and charges in coulombs, the unit of electric intensity is one *newton per coulomb.*

You can also express the unit electric field in terms of the force experienced by an electron. The unit electric field at a point is that field which will exert a force of 1.6×10^{-19} newton on an elementary charge (electron) placed at that point. It acts in a direction opposite to the direction in which the electron tends to move. This is because an electron carries negative charge.

Exercises

(1) What will be the force experienced by a proton when placed at a point where the intensity of the field is 1 N/C? In which direction will it act?

(2) Two equal and opposite charges, $+Q$ and $-Q$, are at points A and B where AB=2l. Such a pair of equal and opposite charges is called a dipole. What is the intensity of the field at a point P on the extension of the line AB at a distance r from the mid point of AB? (Hints-neglecting l^2 which is very small as compared to r^2 when the charges are close to each other prove that $E=2KM/r^3$ along PB, where, M is equal to Q.2l and is called the dipole moment *i.e.* M is the product of the charge and 2l the distance between the two charges).

(3) Calculate the Coulomb force between two point charges each of magnitude 1C separated by a distance of 1 m in vacuum.

(4) Calculate the electrostatic force between two alpha particles (positive charge) each of magnitude $3\ 2\times 10^{-19}$C placed at a distance of 10^{-13} cm apart. If the mass of the particles is $6\ 4\times 20^{-27}$ kg, find the gravitational force between them. The value of G is equal to $6\ 67\times 10^{-11}$ m^3 kg^{-1} s^{-2}. How large is the electrostatic force in comparison with the gravitational force?

(5) In a hydrogen atom, the electron is at a distance of 5×10^{-11} m from the nucleus. What is the electric intensity on the electron due to the nucleus of the atom containing a proton having a charge 1.6×10^{-19} C? Calculate also the force between the two charges.

(6) Two positive charges, one of 40μC and the other of 10μC are separated by a distance of 6 cm. At what point or points, will the total electric intensity be zero?

(7) Similar charges Q and q are placed at A and B. Find a point P on AB at which the electric intensity is zero, when, (i) Q=q, (ii) Q=2q and (iii) Q=4q.

(8) A charge of 2×10^{-6} C placed in an electric field experiences a force of magnitude 0 08 N What is the magnitude of the field?

(9) A charge of 0 52×10^{-6} C is placed in an electric field of 4.5×10^{-5}C N/C. What is the magnitude of the force acting on the charge?

8.7 Electric Field due to Point Charges

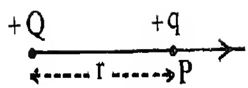


Fig 8 5

Consider the electric field at a distance r from an isolated positive point charge of magnitude Q. Imagine a small positive test charge q placed at that point. Then, according to the Coulomb's law, this test charge is repelled by the charge Q with a force given by (figure 8.5),

$$F = K \frac{Q\,q}{r^2}.$$

Hence, the electric intensity at the point is,

$$E = \frac{F}{q} = \frac{KQ}{r^2} \frac{\text{Newton}}{\text{Coulomb}}.$$

From the above, it follows that the electric intensity due to a charge falls off inversely as the square of the distance from it. It is strong near the charge and rapidly falls off at points farther away

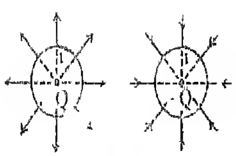


Fig 8.6

The electric intensity at any point on the surface of a sphere of radius r drawn with the point charge Q at the centre is given by the equation, $E = KQ/r^2$. The field intensity is directed radially outwards if Q is a positive charge and radially inwards if Q is a negative charge (figure 8.6)

8.8 Lines of Force

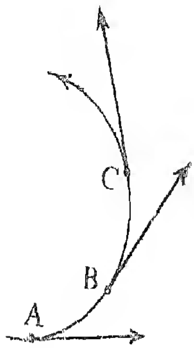


Fig 8.7

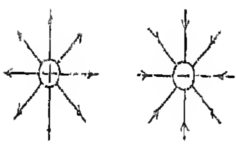


Fig. 8 8

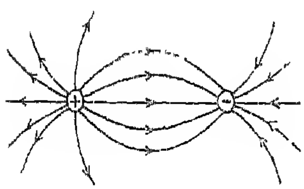


Fig 8.9

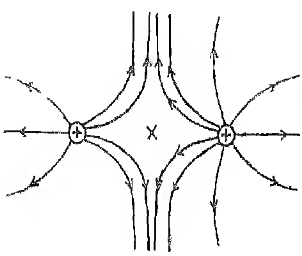


Fig. 8.10

Michael Faraday (1791-1867) introduced the idea of lines of force to explain the properties of an electric field. If a free positive test charge is placed at any point in an electric field, it will experience a force. Since, it is free, it will begin to move in the direction of the electric intensity at that point. The path along which a free positive charge moves in an electric field is called a *line of force*. This direction is indicated by an arrowhead on the line. If the direction of electric field changes from point to point, the line of force will be curved. The tangent at every point to this curved path gives the direction of the electric field at that point, (figure 8.7). It follows from the above that the lines of force diverge from a positive charge and converge towards a negative charge (figure 8.8). The examples of lines of force due to,—

(i) two charges of equal magnitude but opposite in sign,

(ii) two equal and positive charges, and

(iii) two oppositely charged plates placed close and parallel to each other are shown in figures 8.9, 8.10 and 8.11 respectively.

The number of lines of force that can be drawn originating from a positive charge are infinite, since there is a line of force through every point in an electric field. From the above figures you will see that the lines of force are close together where the field is strong and far apart where the field is weak. The electric field intensity at a point is proportional to the number of lines of force passing through a unit area normal to the field.

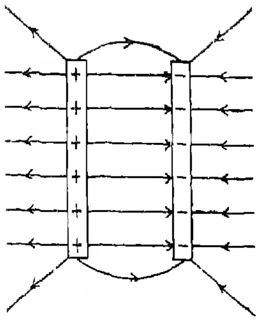
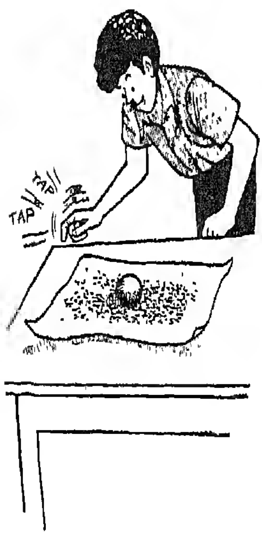


Fig 8.11

In a region of uniform field (figure 8.11) these lines of force are parallel and equidistant. A uniform field is one in which the direction and the magnitude of the field is the same every where.

Activity

Place a sheet of paper on a table. Sprinkle lightly a layer of dry and fine saw dust on this sheet of paper. Charge a metal ball suspended with a silk thread by touching it with a charged glass rod. Do not touch the charged ball. Place the metal ball on this paper. Tap the table gently. Observe what happens to the saw dust particles. The particles move little and settle down in a certain pattern. Try to draw the pattern on a piece of paper.



Repeat the experiment using two metal balls placed at a small distance apart (a) when they are similarly charged, and (b) when they are oppositely charged.

Repeat the experiment with a charged metal rod or a charged glass rod in place of the ball, (a) when the rod is vertical and (b) when the rod is horizontal.

8.9 Some properties of lines of force

A line of force originates from a positive charge and ends on a negative charge. A line of force will extend till it meets a surface which is charged negatively. Lines of force in an electric field can never intersect. This is because electric field at any point can have only one direction, the direction in which a unit positive charge

would experience a force, if placed at that point. Hence only one line of force can pass through each point in an electric field.

8.10 Electrical potential difference and potential energy

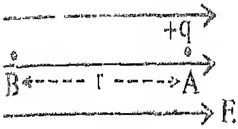


Fig. 8.12

Consider a charge $+q$ at a point A in a uniform electric field of intensity E (figure 8.12). The charge $+q$ experiences a force $F=qE$ along the line of force. If the charge at A is to be moved to a point B against the direction of the electric field E, you will have to do some work against the force qE. If the point B is at a distance r from A then the work done W in moving the charge from A to B is

$$W = F.r$$
$$= q.E.r.$$

So, when the charge is brought to B from A, it has gained in potential energy by an amount equal to q.E.r. But if the same charge is brought to A from B, it loses an equal amount of potential energy. Therefore q.E.r is the difference of potential energy of the charge between the points B and A. Electrical potential difference is defined as the change in the electrical potential energy per unit positive charge. The *potential difference* V (p.d.) between the points B and A is, therefore, given by

$$V = \frac{q.E.r}{q}$$
$$= E.r.$$
$$= \text{field intensity} \times \text{displacement}.$$

Since energy is a scalar quantity, potential difference is also a scalar quantity. It is measured in energy per unit charge. As energy is expressed in Joules and charge in Coulombs, the potential difference V is expressed in Joules/Coulomb or J/C. This unit is called *Volt*, and is generally denoted by V.

Question

From the relation between V and E as given above and the units of E and V already stated, show that the field intensity E can be expressed as volt per metre.

If q be the electronic charge (1.6×10^{-19} C), the energy acquired by an electron when it falls through a potential difference of 1 volt, is equal to 1.6×10^{-19} joules. This energy is called an *electron Volt* (eV), a term widely used in expressing energy in atomic physics. Similarly, there are units such as keV, MeV, as kilo and mega electron volts.

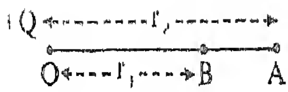


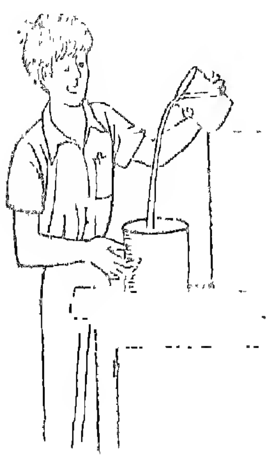
Fig 8.13

If you have a charge +Q at a point O, and B and A are two points in the field of the charge (figure 8.13), then the intensity of the field at B is KQ/r_1^2 and that at A is KQ/r_2^2. As r_2 is greater than r_1, the field intensity at B is greater than that at A. So, the potential at B is higher than the potential at A, since work is to be done against the electric force to move a unit positive charge from A to B. So, electric field as well as potential are greater at points near the positive charge and smaller at points farther away from it. You can, therefore, say that any field of force, gravitational or electrical is associated with two important quantities, namely,

(i) a field intensity at every point, and

(ii) a potential at that point.

A positive potential difference between B and A means that the energy of a positive charge is greater at B than at A. On the other hand, a negative potential difference between B and A means that its energy is less at B than at A. This means that, the point B in the electric field is at a higher potential than the point A in the same field.



Hence, a charge left free at B tends to move towards A. That is positive charge flows from higher to lower potential This is similar to the fall of a body or the flow of a liquid in the earth's gravitational field.

8.11 Equi-potential Surface and Lines of Force

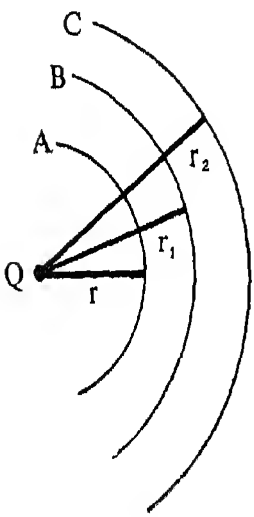


Fig. 8 14

Imagine a sphere of radius r drawn round a point charge +Q. As every point on the surface of the sphere is at a distance r from the charge Q and the lines of force are radial, the potential at any point on the surface of this sphere is the same. Such a surface which has the same potential at every point on it is called an *equi-potential surface*. The surface of the sphere A (figure 8.14) is an equi-potential surface. Similarly surfaces of spheres like B, C etc., are each an equi-potential surface, the potentials at every point on their surfaces are respectively, KQ/r_1, KQ/r_2, etc., where r_1 and r_2 are the radii of the spheres B and C respectively. Therefore, in such a case, the electric field is assumed to be consisting of equi-potential surfaces round the charge. The magnitude of the electric-field will be the same at every point on a spherical equi-potential surface. The field, being radial, is in a direction perpendicular to the equi-potential surface in the above case, and so the lines of force are normal to the surface. You will learn later on that this is a very general result which holds good for all equi-potential surfaces of all shapes. An electric charge moves in the direction of line of force. So, an electric charge cannot be moved by the field from one point to another on an equi-potential surface.

Charge moves from a point of higher potential to another point at a lower potential. It is the potential difference between the two points in an electric field that determines the direction of flow of charges.

Questions

(1) *A particle carrying a charge of 10^{-5} C starts moving from rest in an electric field of uniform intensity 50 V/m,*

(i) *What is the force on the particle?*

(ii) *How much kinetic energy will the particle have after it has moved 1 m?*

(2) *A, B, and C are bodies having potentials +50V, +30V and —30V respectively. Find the potential difference (p.d.) between (i) A and B (ii) B and C and (iii) C and A.*

(3) *What is the energy in electron volt of an electron whose speed is 10^6 m/s?* (Mass of an electron in 9 1 $\times$ 10^{-31} kg).

(4) *What is the speed of an electron whose energy is 50 eV?*

9.1 Potential difference

When you raise an object to a certain height, you do some work in doing so against the force of gravity. When you climb upstairs a few floors, you feel quite tired as if you have done some hard work. This is because you have to do work in going from a lower to a higher level against the force of gravity. The work done in raising a unit mass against gravity is called gravitational potential. Thus if a body of unit mass is raised through a vertical height h against the force of gravity, then the potential energy possessed by the body at the height h will be gh. If instead of raising the mass vertically, you raise it along any other path the work done will depend only on the difference in vertical heights through which it is moved and not on the actual path followed. At another height h′, it will be gh′. Thus if two points A and B are at heights h and h′ respectively, the gravitational potential difference between them is g (h′—h) (figure 9.1).

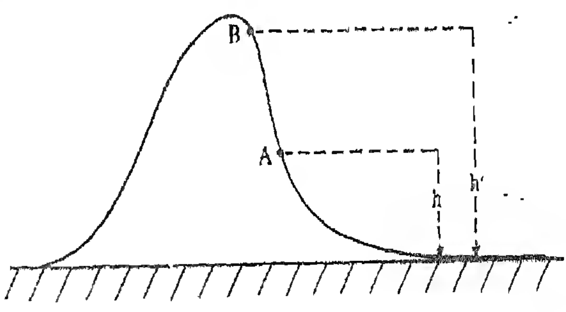


Fig 9 1

When you release an object from a height, it always falls downwards. When a body at B, is allowed to fall freely along the slope it will move towards A and not towards any higher point above B. In other

words, it will move from higher to lower potential. Thus a river flows from mountains down into the plains. It cannot flow upwards.

Similarly a potential difference must exist for the flow of electric charges. The potential difference between two points, say B and A in an electric field is defined as the amount of work that must be done in order to move a unit charge from A to B. You, therefore, find that any field of force, gravitational, electrostatic, etc., is associated with the two important quantities, (a) field and (b) potential. Bodies left to themselves will fall from a higher level to a lower level. In the same way, charge left to itself will flow from higher potential to lower potential. Similarly, heat also flows from higher temperature to lower temperature.

9.2 Flow under potential difference

Activity

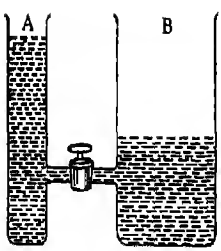


Fig 9.2

(1) Take two vessels A and B connected by a tube having a stop-cock as shown in figure 9.2. Pour some water in each of the vessels so that the levels are not equal Add few drops of ink to the vessel A Open the tap In which direction does the water flow? Does it move from the higher level to the lower level? You will find that the water always moves from the vessel with a higher level to the vessel with a lower level You will also observe that the movement of water continues till the water levels in the two vessels become the same. From this experiment you find that water flows from a higher level to a lower level

because there exists a difference of gravitational potential between the two levels

(2) Take a metal rod and put some wax along the length of the rod Keep one end of the metal rod in a block of ice, as shown in figure 9.3 Heat the other end by a spirit lamp. What happens to the metal rod and the

Fig 9.3

block of ice? You will find that as you heat it, the wax starts melting. The one nearer the heated end melts first, then the next and so on After some time you will find that ice will also start melting Does this show that heat flows from a body at a higher temperature to a body at a lower temperature?

(3) Take a beaker and fill it with water. Note down the temperature of the water. Take a metal ball provided with a hook and suspend it by means of a thin wire (figure 9.4). Put the

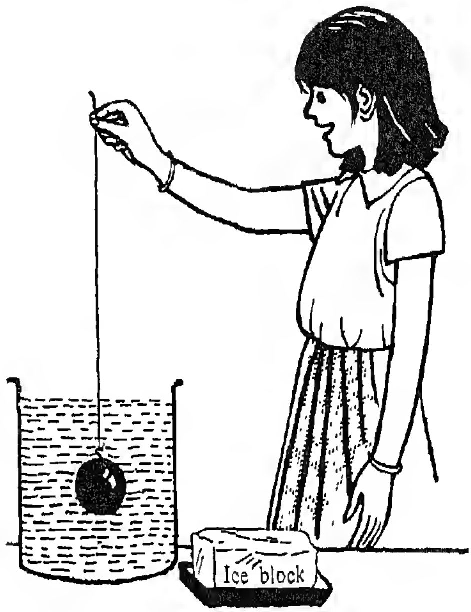


Fig 9.4

ball on a block of ice. Keep it for some time and immerse it in the beaker. Repeat this a number of times and measure the temperature of water with a thermometer. What happens to the water? Does it become cold? Where has its heat gone? Has it flown from water to the metal ball? Heat the metal ball over a flame and immerse it again in water. Repeat this a number of times and note the temperature of water. Does it become warm? Has the heat flown from the ball which is at a higher temperature to the water which is at a lower temperature?

(4) Take a cell and connect it to a bulb through a key, as shown in figure 9.5. Place a compass needle beneath the connecting wire.

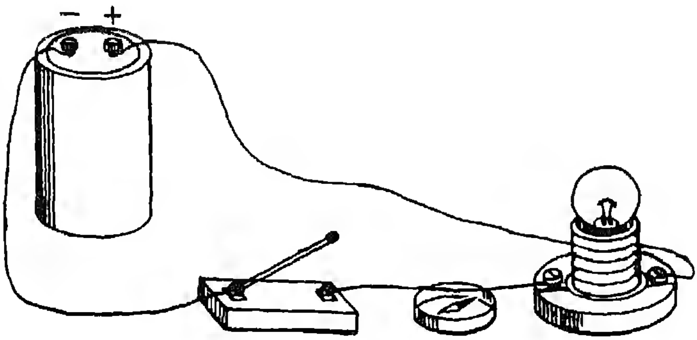


Fig. 9 5

Put on the key. What happens to the compass needle? You will find that the needle is deflected in some direction. You know that the + marked terminal of the battery is at a higher potential Now reverse the connections Put the key again. Note the direction in which the needle deflects. What does this suggest? Does it suggest that the current flows from the + terminal to the negative terminal. This means that the current flows from a body at a higher potential to a body a lower potential.

From the above experiments you find that whether it be water, heat or electricity, flow takes place only when there is a potential difference.

9.3 Resistance

Again take the case of water flowing from one vessel to another. You will observe that it takes some time for water to flow from one vessel to another before the levels become the same. Now you will see that the flow of water depends on the potential difference (height

in the limbs) and also on the area of cross section of the connecting tube. If the connecting tube has a narrow bore, time taken for water to flow out will be more. This is because there is a resistance to the flow of water. The same is true for the flow of heat or electric charge. In these cases also, if the connecting rod or wire is very thin, the time taken for the flow will be more. Call this the resistive flow under potential difference Now try to understand this aspect in some details starting again with the water and a vessel provided with a narrow tube. Use your model to explain various phenomena connected with the resistive flow.

Take a vessel provided with a narrow tube and a stop-cock as shown in figure 9.6. Cut a thin strip of

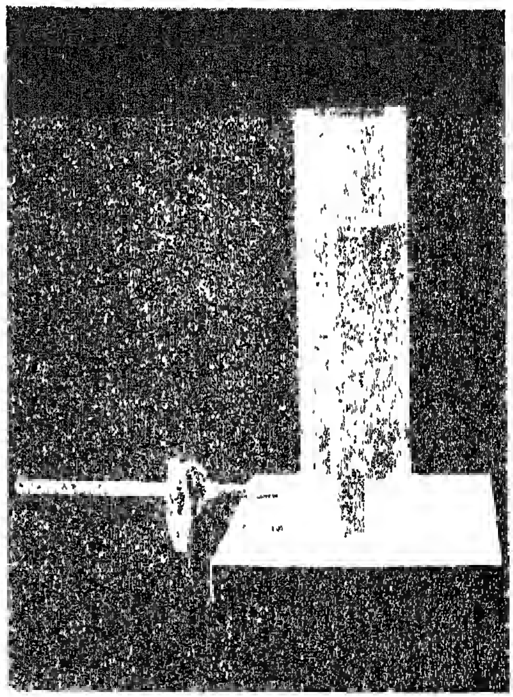


Fig. 9.6

graph paper and paste it on the vessel as shown. You can now read the height of the water column very easily. Put some water in the vessel and note the height. Open the stop-cock. The water falls drop by drop Collect this water in a measuring jar.

Note the volume of water flowing per minute. The level of water in the vessel gradually falls down. Note the level of water before and after the flow and calculate the mean level h. Care should be taken that the level difference is not much. The presure of water p is given by hdg where d is the density of water and g the acceleration due to gravity. Note the volume of water flowing through the tube per minute for various heights of water in the vessel. Record your observations as under:

No. of obs	Volume of water flowing per minute (V)	Level before	Level after	Mean level (h)	Ratio $p/V = \frac{hdg}{V}$ N s/m^5
1 2 3		16.0 cm			
1 2 3		14.0 cm			
1 2 3		12.0 cm			

Plot a graph taking pressure (hgd) of water-column which causes the flow along Y-axis and the corresponding volume of water collected per minute along X-axis. You will get a graph as shown in figure 9 7. The amount of water collected per minute gives the rate of flow of water. Find the ratio between the pressure and

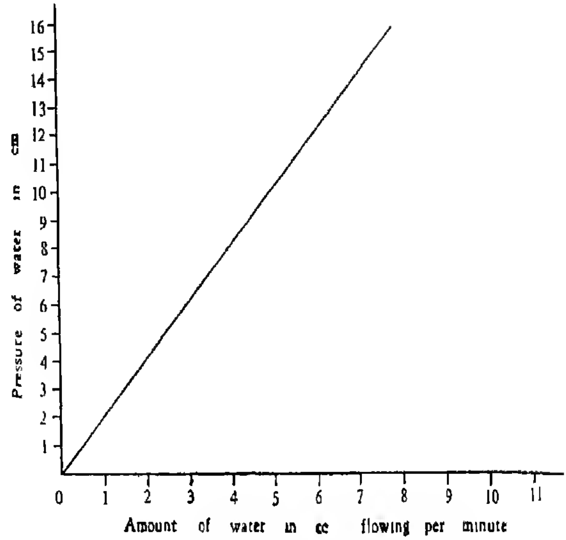


Fig. 9.7

the corresponding rate of flow. The ratio is found to be approximately constant and is defined as the resistance of the tube. Find the resistance both from the graph and also from experimental data. Do you find any difference in the two values?

Activity

Take a conductor PQ represented by sawlines in figure 9.8. Connect PQ to one or two cells, an ammeter and a key. In an electrical circuit a cell is represented by the sign —|⊢ where the longer arm represents the positive and the shorter arm the negative terminals respectively. The circle with an arrow inside and labelled by the letter A, represents an ammeter. When the circuit is ON, current flows through the circuit and the needle of the ammeter is deflected. Note down this deflection. Now insert one more cell in the circuit. For larger current you get larger deflections. Repeat this

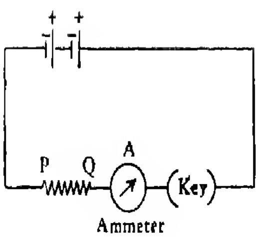


Fig. 9.8

experiment with three, four and more cells. Note down the deflection of the ammeter needle in each case in a table as shown below:

Potential difference V	Current I	$\frac{V}{I}$
1.5 3 0		
4.5 6.0		

Draw a graph plotting current in ampere along Y-axis and the potential difference in volts along X-axis. What type of graph do you get? What is the value of the ratio in each case?

(2) Take a metal piece and place a brass slab over it (figure 9 9) Take some ice in a beaker and place this beaker on the brass slab. Heat the metal piece by a spirit lamp. You will find that as the metal piece becomes gradually hot, the ice starts melting. You will find that after some time, the ice is melting at a constant rate. The flow of heat from hot metal piece to the ice slab will depend on the thickness of the brass slab. If you introduce a very thin slab, then flow will be faster than when a thick slab is introduced. You, therefore, find that the flow of heat depends on the thickness of the brass slab in between.

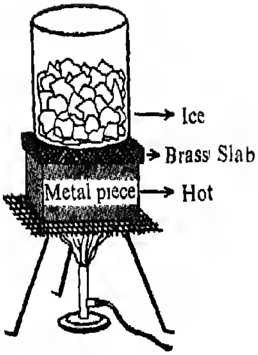


Fig. 9 9

9.4 Resistance of flow through a narrow tube depends on length and the diameter of the tube

(a) Resistance depends on length

Take the vessel again. Suppose the length of the

tube is 10 cm. (figure 9.6). Note the amount of water flowing through the narrow tube per minute for various heights of water in the vessel. Find the ratio p/V for each set of readings.

Take another narrow tube of the same cross-section and about 10 cm. in length. Join it to the first tube by means of a cork as shown in figure. 9.10.

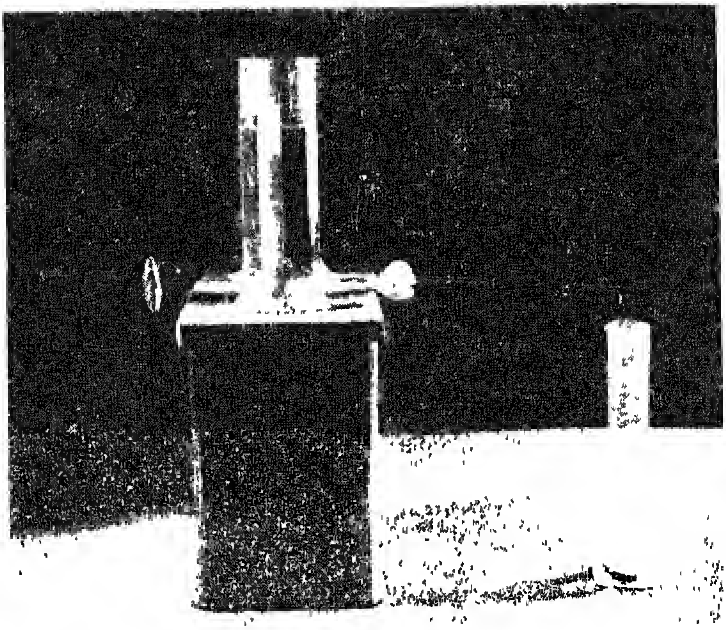


Fig. 9.10

The total length of the two tubes is now 20 cm. Find the amount of water flowing through the tubes per minute for various heights of water in the vessel. Find the ratio p/V again.

Next, take another similar tube of 10 cm. length and connect the three tubes together. The total length is now 30 cm. Find the ratio p/V again. Do you find any difference in the three sets of observations? Do you find that the resistance to the flow of liquid depends on the total length of the tube?

(b) Resistance to the flow depends on the diameter of the narrow tube

Take the vessel again. Suppose the tube A has a diameter 0.2 cm. Note the amount of water flowing through the tube per minute for various heights of water in the vessel. Find the ratio p/V for each set of readings.

Now instead of tube A, use the tube B of diameter 0.4 cm. Find again the amount of water flowing per minute for various heights of water in the vessel. Find the ratio p/V for each set of readings. Do you find any difference in the values? Does it show that resistance to the flow of liquid depends on the diameter of the tube?

9.5 Resistances in parallel

Take the vessel again. Water is allowed to flow through both the tubes A and B as shown in figure 9.11.

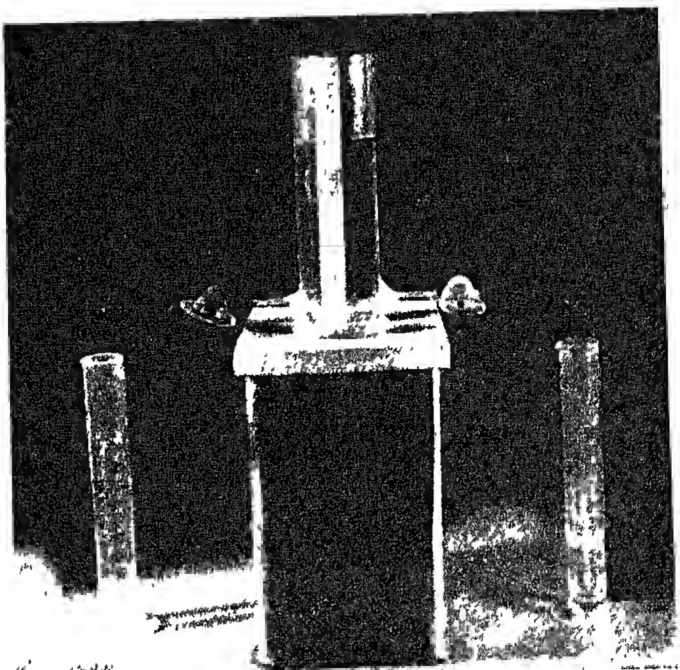


Fig. 9.11

The volume of water flowing per minute is found by keeping two graduated cylinders below the tubes. Find the volume of water flowing for various heights and the ratio p/V in each case In one such experiment following observations were recorded.

Tubes A and B in parallel

No. of obs.	Amount of water flowing/minute (V)	Level before	Level after	Mean level (h)	Ratio $p/V = hdg/V$ $\frac{N.s}{m^5}$	Resistance R
1	37 cc	16·0 cm	15 1 cm	15 55 cm	0 29	0 29
2	,,	,,	,,	,,	,,	
3	,,	,,	,,	,,	,,	
1	32.5 cc	14.0 cm	13.4 cm	13.7 cm	0.29	0.29
2	,,	,,	,,	,,	,,	
3	,,	,,	,,	,,	,,	
1	21 cc	10 0 cm	9.6 cm	9 8 cm	0 29	0.29
2	,,	,,	,,	,,	,,	
3	,,	,,	,,	,,	,,	
1	18 5 cc	8.0 cm	7 7 cm	7 85 cm	0 29	0 29
2	,,	,,	,,	,,	,,	
3	,,	,,	,,	,,	,,	
1	14 cc	6.0 cm	5 8 cm	5 9 cm	0 29	0 29
2	,,	,,	,,	,,	,,	
3	,,	,,	,,	,,	,,	

Resistance of the tube A may be taken as = 0 84 N s/m^5
Resistance of the tube B = 0.40 N s/m^5
Resistance of tube A and B in parallel = 0 29 N s/m^5

It is seen that the effective resistance is related to the individual resistances as given by the formula

$$1/R = 1/R_1 + 1/R_2.$$

Resistance R calculated from the formula was found to be $= 0.27$N s/m^5.

Resistance R determined experimentally $= 0.29$ N s/m^5.

The resistance calculated is in fair agreement with the experimentally determined value. It may be mentioned that there is a similar relation for electrical resistances. Indeed, for any flow such a law should hold good.

9.6 Resistance in Series

Take a vessel with water inside it and provided with a narrow tube (figure 9.6). Open the stop-cock of the vessel. Collect water in a graduated cylinder kept below the tube. Find the height and the volume of water flowing per minute for different heights of water in the vessel. Now replace the tube of the vessel by a second one and find again the volume of water flowing/min. for different heights. From that find the resistances R_1 and R_2 of the two tubes. Now join the two tubes as shown in figure 9.10 and repeat your experiment as before Record your observations in tables I, II & III as shown below.

Table I

Tube A

No. of obs.	Amount of water flowing/ minute (V)	Level before	Level after	Mean level (h)	Ratio p/V= $\frac{hdg}{V}$ N s/m^5	Resistance R_1
1 2 3		16 cm				
1 2 3		14 cm				
1 2 3		12 cm				
1 2 3		10 cm				
1 2 3		8 cm				

Table II

Tube B

No of obs.	Amount of water flowing/ minute (V)	Level before	Level after	Mean level (h)	Ratio $\frac{p}{V}=\frac{hdg}{V}$ N. s/m^5	Resistance R_2
1 2 3		16 cm				
1 2 3		14 cm				
1 2 3		12 cm				
1 2 3		10 cm				
1 2 3		8 cm				

Table III

Tubes A and B in series

No. of obs.	Amount of water flowing/ minute (V)	Level before	Level after	Mean level (h)	Ratio $\frac{p}{V}=\frac{hdg}{V}$ N s/m^5	Resistance R
1 2 3		16 cm				
1 2 3		14 cm				
1 2 3		12 cm				
1 2 3		10 cm				
1 2 3		8 cm				

From table III, plot a graph between pressure p and the volume of water collected per minute i.e. the rate of flow. From the graph find effective resistance R. Does this result agree with the one found from the table? Does this also agree with the results calculated from the relation $R = R_1 + R_2$? The values of R_1 and R_2 have been found from table I and table II.

9.7 Half life

Water is filled in the vessel to a certain mark. The stop-cock is opened and water collected in a graduated cylinder (figure 9.6). The level of water in the vessel is noted at various times. In an actual experiment following observations were recorded.

No. of obs.	Initial level	Time in min	Level in cm.
1	18.0 cm	5 min	15.8 cm
2		10 ,,	13 9 ,,
3		15 ,,	12.5 ,,
4		20 ,,	11 5 ,,
5		25 ,,	10.9 ,,
6		30 ,,	10.3 ,,
7		35 ,,	9 7 ,,
8		40 ,,	9 1 ,,
9		45 ,,	8 6 ,,
10		50 ,,	8 1 ,,
11		55 ,,	7.6 ,,
12		60 ,,	7.1 ,,
13		65 ,,	6.7 ,,

If a graph is plotted between the time in minute and pressure in cm. you get a curve of the type shown in figure 9.12.

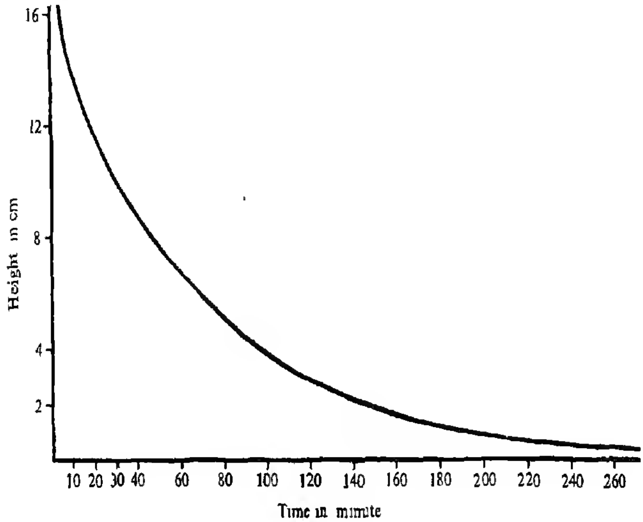


Fig 9 12

From the graph it is clear that the time required for the level to fall from, say 16 cm. to 8 cm. is the same as the time required for the level to fall from 8 cm. to 4 cm. or from 4 cm. to 2 cm. This is the characteristic time and call it as *half life*.

The half life of a mass of liquid flowing out through a tube is the same. Suppose the total mass of the liquid in the vessel is 200 g, and half of this mass, i.e. 100 g is allowed to flow out. It takes, say about 60 minutes to do so. The mass remaining in the vessel at that time is 100 g. If now half of this mass, i.e. 50 g is allowed to flow, it is found that it also takes 60 minutes to flow through the tube. If now 25 g flow out, it is found that the time taken is again 60 minutes. This shows that half life of a mass of liquid flowing through a tube is the same.

You find similar behaviour in a *radioactive* substance. A radioactive substance like radium, uranium, etc., spontaneously breaks up giving out radiations. This breaking or disintegration is called *radioactive decay*. In this radioactive decay, the half life of a particular radioactive substance remains the same. This time may be several seconds for some substances while for some other substances this half life may be millions of years. This half factor in a radioactive substance has helped to determine the age of the earth, the age of rocks and of fossils of ancient animals and plants embedded in rocks. Uranium present in rocks, in course of its radioactive decay, forms lead and helium This process has been measured very accurately and the amount of lead formed from a certain amount of uranium gives a measure of the age of the rocks. Radioactive carbon has been used to determine the age of fossil. You will learn more about radioactivity as you advance in the study of Physics.

Activity

Take a graduated cylinder fitted with a narrow tube near its base. The tube has got a stop-cock to control the flow of water. Now with this apparatus, see how water flows out through the tube. Fill the cylinder nearly full with water Mark the level of water accurately and record the height h_1. Allow water to flow out for quite some time (it may be half an hour or more and you need not record time, nor is it necessary that you be looking at it all through). Then, close the stop cock and record the level of water h_2 accurately. From these two readings, find from the h-t (height—time)

graph, the time for the level of water to fall from h_1 to h_2. Does this provide a method of finding the time-interval of an event?

9.8. Flow of liquid into successive vessels

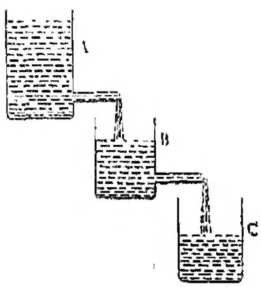


Fig 9.13

Take three vessels A, B and C and arrange them as shown in figure 9.13. A is at a higher level than B and B is at higher level than C. Allow the water to flow out from the vessel A to B and then to C. You will find that as the level of liquid in A is falling, the level of liquid in B shows a rise from zero to a certain value. After some time, however, the level of liquid in B remains steady. See how this happens. Liquid from A flows into B. From B also liquid flows into C. So, at first more liquid flows into B than flowing out from B to C. At the steady state, the mass of liquid flowing into B is the same as the mass of liquid flowing out from B to C. Then a *transient equilibrium* is reached. Such a thing usually happens in radioactive substances where a similar sort of equilibrium is reached when a radioactive substance A decays into B and then to C. You will learn more about it in future.

Dear Reader,

We have great pleasure in sending you a copy of the experimental edition of the Physics text book for the age group 12+(class VII).

With the explosion of knowledge connected with science and technology, it has been realised all over the world that the teaching of Physics at elementary levels should be based more on an experimental approach which, it is hoped, will provide a sense of inquiry in the young minds. For the first time in our country, a large section of physicists in the universities are collaborating in the programme of improvement in Science education in schools. This book is a result of this collaboration. The authors are well aware of the shortcomings in this book which have resulted out of the short time at their disposal in getting out this experimental edition.

The volume is being sent to you with a definite purpose. It is needless to say that your constructive suggestions for its improvement will go a long way in revising this experimental edition and bringing out the first set of books on Physics for Indian schools With this objective we enclose a questionnaire which you may kindly fill after studying the book and return it to us.

Yours sincerely

V. G. BHIDE

National Physical Laboratory
New Delhi 12

COMMENTS ON THE NCERT PHYSICS ST

Name, designation and address
of person making comments.

Date

(If the space provided against the question is not sufficient please attach additional sheet. In your comments, pleas
a comment is primarily based).

Chapter	I	II	III	IV	V
1 Is the matter presented in the chapter comprehensible to the students of the age group to which it is intended? If not, what are the portions which you consider as above the standard? How should these be modified to suit the students' comprehension? Would you suggest any addition to the text?					
2. Do you think that the development of concepts are natural and continuous? Are there any places where it appears to be abrupt? Suggest how these could be improved					
3. Do you think that the approach to the topic is such as would induce curiosity and a sense of inquiry in the mind of the student? If not, what modifications should be made to achieve this?					
4 Do you think the language is simple enough? If not, kindly make concrete suggestions Indicate the places where the language should be changed.					
5 Do you think there are places where the meaning is not clear/is ambiguous/confusing? If so, indicate the places. How can they be improved?					
6 Do you think that the practical experiments suggested are adequate and bring out the desired results? If not, what additional experiments would you like to suggest					